INDIAN ROADS CONGRESS

(Established 1934.) (Registered 1937.)

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(1938.)

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10. Mr. H. B. Parikh, Special [illegible] Works Department, Karachi [illegible]

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13. Mr. V. P. Bedekar, State Engineer, Miraj, (Deccan States Agency).
14. Rao Bahadur K. J. Gandhi, State Engineer, Junagadh State, (Western India States Agency).
15. Mr. M. T. Adalja, Chief Engineer, Baroda State, Public Works Department, Baroda.
16. Mr. Dilbagh Singh Dhesi, State Engineer, Jind State.
17. Mr. G. B. E. Truscott, Chief Engineer, Travancore State, Trivandrum.
18. Diwan Bahadur N. N. Ayyangar, Chief Engineer of Mysore, Public Works Department, Bangalore.
19. Mr. G. P. Bhandarkar, Chief Engineer, Holkar State, Indore.
20. Mr. H. E. Ormerod, Associated Cement Companies Limited, Forbes Building, Home Street, Bombay.
21. Colonel G. E. Sopwith, Shalimar Tar Products (1935) Limited, 6 Lyons Range, Calcutta.
22. Mr. C. D. N. Meares, Standard Vacuum Oil Company, Calcutta.
23. Mr. W. A. Griffiths, C/o Burmah Shell Oil Company, Limited, Hongkong House, Calcutta.
24. Lieutenant Colonel H. C. Smith, O.B.E., M.C., M.L.A., General Secretary, Indian Roads and Transport Development Association, 41 Nicol Road, Bombay.
25. Mr. N. V. Modak, City Engineer, Bombay Municipality, Hornby Road, Fort, Bombay.
26. Mr. Dildar Hussain, Assistant Chief Engineer, His Exalted Highness the Nizam's Public Works Department, Hyderabad (Deccan).
27. Mr. A. Lakhshminarayana Rao, District Board Engineer, Masulipatam, Kistna District.

Proceedings of the Fourth Meeting of the Indian Roads Congress.

Vol. IV. HYDERABAD (DECCAN) JANUARY 1938.

APPENDICES.

Proceedings of the Fourth Meeting of the Indian Roads Congress held at Hyderabad (Deccan) on January 4 to 6, 1938.

The Fourth Session of the Indian Roads Congress commenced at 11-45 a.m. on January 4, 1938, at the Town Hall, Hyderabad (Deccan). The following members of the Congress were present:—

Madras Presidency.

M. R. Ry. A. Nageswara Ayyar Avergal, Special Engineer, Road Development, Madras.

Mr. A. W. Nightingale, Superintending Engineer, Bellary Circle, Bellary.

Mr. V. H. Sadarangani, Professor of Civil Engineering, College of Engineering, Guindy.

Mr. P. G. Mathew, District Board Engineer, Nellore, South India.

Mr. N. Durrani, District Board Engineer, Bobbili.

Mr. B. Narasimha Shenoy, District Board Engineer, Calicut, Malabar District.

M. R. Ry. A. Lakshminarayana Avergal, District Board Engineer, Kistna District, Masulipatam.

Mr. N. P. Sundaram Pillai, District Board Engineer, Negapatam.

Mr. T. Lokanathan Mudaliyar, District Board Engineer, Coimbatore.

Mr. K. S. Raghava Chary, Assistant to Special Engineer, Road Development, Madras.

Mr. K. Tirumalai Swami Ayyar, District Board Engineer, Saidapet.

Mr. S. Srinivasa Raghavacharyar, District Board Engineer, Trichinopoly.

Mr. B. Satyanarayana, District Board Engineer, Rajahmundry.

Mr. G. B. Sankaram, Local Fund Asst. Engineer, Amlapuram.

Mr. S. R. Panje, District Board Engineer, Anantapur.

Bombay Presidency.

Mr. R. A. Fitzherbert, Superintending Engineer, Road Development, Bombay Presidency, Bombay.

Mr. N. V. Modak, City Engineer's Office, Bombay Municipality, Fort, Bombay.

Mr. E. A. Nadir Shah, Hydraulic Engineer, Bombay Municipality.

Mr. V. M. Sukhatankar, District Engineer, District Local Board, Belgaum.

Mr. G. D. Daftari, Executive Engineer, Poona Division, Poona.

Mr. M. D. Wale, District Engineer, Hubli Municipal Borough, Dharwar.

Bengal.

Mr. A. N. Bose, Superintending Engineer, Calcutta.

Mr. J. C. Guha, Executive Engineer, Dacca Division, Dacca.

United Provinces.

Mr. Mahabir Prasad, Executive Engineer, Agra.

Mr. A. Eastmond, Executive Engineer, Naini Tal.

Rai Sahib Fateh Chand, Secretary-Engineer, District Board, Bijnor.

Mr. H. S. Sharma, District Board Engineer, Meerut.

Punjab.

Mr. S. G. Stubbs, O.B.E., Chief Engineer and Secretary to the Government of the Punjab, Public Works Department, Buildings and Roads Branch, Lahore.

Mr. R. Trevor Jones, M.C., Superintending Engineer, Third Circle, Public Works Department, Lahore.

Bihar.

Mr. W. L. Murrell, Superintending Engineer, Chota Nagpur Circle, Ranchi.

Rao Sahib M. A. Rangaswami, District Engineer, Darbhanga.

Central Provinces.

Mr. C. B. Roy, Executive Engineer, Chhindwara.

Mr. G. M. Mckelvie, Executive Engineer.

Mr. K. B. Dewasthala, District Engineer, District Council, Yeotmal.

Assam.

Mr. Ali Ahmed, Superintending Engineer, Public Works Department, Shillong.

Mr. Raj Mohan Nath, Assistant Engineer, Public Works Department, Nowgong, Assam.

North West Frontier Province.

Captain R. C. Graham, R.E., Executive Engineer, Public Works Department, Peshawar.

Orissa.

Mr. R. C. Hewitt, Superintending Engineer, Public Works Department, Orissa, Cuttack.

Mr. C. M. Bennett, Executive Engineer, Koraput Division, Koraput.

Sind.

Mr. H. B. Parikh, Special Road Engineer in Sind, Karachi.

Mr. G. B. Vaswani, Assistant Engineer (Roads), Karachi Municipal Corporation, Karachi.

Central Public Works Department.

Sardar Bahadur Teja Singh Malik, C.I.E., Superintending Engineer, Central Public Works Department, New Delhi.

Military Engineers Services.

Brigadier E. C. Walker, Chief Engineer, Southern Command, Poona.

Captain R. Clayton, R.E., Engineer-in-Chief's Branch, Army Headquarters, Simla.

Mr. Iftikhar-ud-Din Mufti, Assistant Garrison Engineer, Fort William, Calcutta.

Government of India.

Mr. L. B. Gilbert, Consulting Engineer to the Government of India (Roads).

Mr. Jagdish Prasad, Assistant to the Consulting Engineer to the Government of India (Roads).

Central India Agency.

Mr. G. P. Bhandarkar, Chief Engineer, Holkar State, Indore.

Mr. T. C. Gue, Chief Engineer, Rewa State.

Mr. C. P. Saksena, Sub-Divisional Officer, Public Works Department, Annuppur, Rewa State.

Hyderabad (Deccan).

Nawab Ahsan Yar Jung Bahadur, Chief Engineer and Secretary to Government, His Exalted Highness the Nizam's Dominions, Drainage and Irrigation Department, Hyderabad (Deccan.)

Mr. Syed Arifuddin, Superintending Engineer, H. E. H. the Nizam's P. W. D. Aurangabad Circle, Hyderabad (Deccan).

Mr. M. Abu Turab, Superintending Engineer, Medak.

Mr. Dildar Husain, Assistant Chief Engineer, H. E. H. the Nizam's P. W. D., Hyderabad (Deccan).

Mr. J. C. Hardikar, Executive Engineer, Public Works Department, Parbhani (Nizam's Dominions).

Mr. M. H. Naqvi, Executive Engineer, Public Works Department, Bhir, Hyderabad (Deccan).

Mr. H. M. Surati, Divisional Engineer (Roads), Hyderabad (Deccan).

Mr. Safdar Ali Shareef, Assistant Engineer, H. E. H. the Nizam's Public Works Department, Hyderabad (Deccan).

Mr. J. S. Narasimham, Roads Supervisor, Town Improvement Trust, Secunderabad.

Mr. M. M. Katrak, 153 Sappers Line, Secunderabad.

Mr. Mohammad Abdul Kayyar Khan, Divisional Engineer, H. E. H. the Nizam's Public Works Department, Kharimnagar District.

Mr. Mohammad Asadullah, Assistant Engineer, H. E. H. the Nizam's P. W. D., Nizamsagar.

Mr. Anwarullah, Superintending Engineer, Osmania University Project, Hyderabad (Deccan).

Mr. Lokendra Bahadur, Executive Engineer, H. E. H. the Nizam's P. W. D., Bidar.

Mr. Mohammad Ibrahim, Executive Engineer, H. E. H. the Nizam's Public Works Department, Asifabad.

Mr. Mirza Mehdi Ali, Assistant Engineer, District Water Works, Hanamkunda, via Kazipet.

Mr. Abdul Hai, Assistant Engineer, H. E. H. the Nizam's P. W. D., Asifabad.

Mr. Faridon S. Chenoy, Executive Engineer, H. E. H. the Nizam's P.W.D., Hyderabad (Deccan).

Mysore.

Mr. N. Sarabhoja, Superintening Engineer, K. E. S. Works, Irrigation Circle, Bangalore.

Mr. N. Subba Rao, Superintending Engineer, Mysore Circle, Mysore.

Mr. N. Lakshminarasimhaiya, Executive Engineer, Bangalore Division, Bangalore.

Mr. K. V. Sreenivasa Murti, Assistant Engineer, No. 1 Sub-Division, Public Works Department, Mysore.

Mr. N. Narasimha Iyenger, Assistant Engineer, No. 2 Sub-Division, Dodballapur, Mysore State.

Gwalior.

Rai. Bahadur S. N. Bhaduri, Chief Engineer, Public Works Department, Gwalior.

Travancore.

Mr. M. S. Durraiswami, Executive Engineer, Kottayam, (Travancore State).

Western India States Agency.

Mr. M. R. Jivarajani, State Engineer, Porbander.

Rao. Bahadur K. J. Gandhi, State Engineer, Junagadh State.

Mr. U. J. Bhatt, State Engineer, Bhavnagar State.

Punjab States.

Mr. Dilbagh Singh Dhesi, State Engineer, Jind State.

Deccan States.

Mr. W. J. Kunte, State Engineer, Jamkhandi

Mr. V. P. Bedekar, State Engineer, Miraj,

Gujarat States Agency.

Mr. S. G. Vaishnav, Public Works Department, Baroda State.

Eastern States Agency.

Mr. F. D, Wellwood, Chief Engineer, Mayurbhanj State.

Business Representatives.

Mr. W. A. Radice, C/o. Messrs. Braithwaite Burn and Jessop Construction Company Limited, Calcutta.

Mr. G. Wilson, C/o. Messrs. Braithwaite Burn and Jessop Construction Company Limited, Calcutta.

Mr. H. E. Ormerod, Associated Cement Companies, Limited Bombay.

Mr. T. R. S. Kynnersley, Concrete Association of India, Bombay.

Rai Sahib Hari Chand, Concrete Association of India, New Delhi.

Mr. W. A. Griffiths, Burmah Shell Oil Company, Calcutta.

Mr. W. L. Campbell, Burmah Shell Oil Company, Calcutta.

Mr. Ian, A. T. Shannon, Burmah Shell Oil Company, Madras.

Lt.-Colonel H. C. Smith, O.B.E., M.C., General Secretary, Indian Roads and Transport Development Association, Bombay.

Mr. C. D. N. Meares, Standard Vacuum Oil Company, Calcutta.

Mr. O. C. Kutty Krishnan, Standard Vacuum Oil Company, Madras.

Mr. N. Das Gupta, Standard Vacuum Oil Company, Calcutta.

Mr. I. N. Khanna, Engineer's House, Chippiwara, Delhi.

Colonel G. E. Sopwith, General Manager, Messrs. Shalimar Tar Products (1935) Ltd., Calcutta.

Mr. W. J. Turnbull, C/o. Messrs. The Shalimar Tar Products (1935) Ltd., Bombay.

Mr. T. Campbell Grey, C/o. Messrs. The Shalimar Tar Products (1935) Ltd., Madras.

Mr. D. Nilsson, C/o. Messrs. J. C. Gammon Limited, Bombay.

Mr. T. W. Stanier, C/o. Messrs. Greaves Cotton Company, Bombay.

Mr. A. G. Senapatty, Bangalore.

Mr. D. H. Ranade, C/o. Messrs. Ranade Brothers, Engineers and Contractors, 653 Budhwar Peth, Poona 2.

Mr. A. Burns Lawson, C/o. The Hindustan Construction Company, Bombay.

Mr. J. P. Anderson, Dunlop House, Calcutta.

A large number of engineer officers of H. E. H. the Nizam's Public Works Department were also present by invitation.

Among the distinguished guests who attended the formal opening of the Congress were the Right Honourable Nawab Sir Hyder Nawaz Jung Bahadur, P.C., Kt., B.A., LL.D., D.C.L., President, H. E. H. the Nizam's Executive Council ; Nawab Sir Aqeel Jung Bahadur, Honourable Member, Military Department ; Nawab Mehdi Yar Jung Bahadur, M.A., (Oxen.), Honourable Member, Political Department ; Sir Theodore Tasker, C.I.E., O.B.E., I.C.S., Honourable Member, Revenue Department ; Nawab Fakhr Yar Jung Bahadur, Honourable Member, Finance Department ; and Nawab Mirza Yar Jung Bahadur, Honourable Member, Judicial Department, Hyderabad (Deccan).

Nawab Ahsan Yar Jung Bahadur (Chief Engineer and Secretary, P. W. D., Irrigation and Drainage, Hyderabad), Chairman of the Reception Committee in welcoming the delegates said :—

On behalf of the Reception Committee, I have the greatest pleasure in welcoming the members of the Indian Roads Congress who have at our invitation come to Hyderabad, capital of the premier state, to hold their annual session here.

With the growth of communications required for the welfare of India as a whole, and Hyderabad in particular, and the rapid increase in mechanised conveyances the construction of durable roads has become

imperative. This subject is at present a complicated and difficult problem and has been engaging the serious consideration of all the Provincial and Central Governments in India and the States.

Gentlemen, road construction nowadays is an expert job and not as of old designed and constructed and maintained by ordinary staff. Great progress has been made throughout the world, especially in America and England, in regard to road-making. In Germany more than 3,000 miles of beautiful cement concrete roads have been constructed recently. The experience gained by Germany after the war has stimulated the growth of rapid communications in preference to railways, owing, most probably, to the quicker and more convenient means of transport both during times of war and peace. Good communications are the index of a nation's greatness and bad roads are cursed by everybody. Considering the number of high officials of the Public Works Department and experienced road engineers congregated here, it is certain they will have great opportunities of pooling their experiences and benefitting by exchange of ideas on all matters relating to the construction and maintenance of highways and bridges, and the objects of the congress will be most successfully established.

Gentlemen, it is with the greatest pleasure I request the Honourable Raja Shamraj Rajwant Bahadur to open the Proceedings of the Fourth Annual Session of the Indian Roads Congress.

THE HONOURABLE RAJA SHAMRAJ RAJWANT BAHADUR, Member H. E. H. the Nizam's Executive Council, in charge of the Public Works Department, in declaring open the Fourth Session of the Indian Roads Congress addressed as follows:—

MR. CHAIRMAN AND GENTLEMEN,

I feel it a great honour and privilege to have been invited to inaugurate this, the Fourth Session of the Indian Roads Congress. It gives me great pleasure to have this opportunity of welcoming to the capital of H. E. H. the Nizam's Dominions so representative and eminent a gathering of engineers.

The Institution of Engineers has just concluded its session in Hyderabad and I have no doubt that the deliberations that took place during the last week and those that are to commence today will contribute greatly to the solution of the many engineering problems that are before our country.

The road problem is a subject of engrossing interest at the present moment. The railway and the steamship, during the past century, have not only brought the peoples of the world together but created in them a desire and an urge for movement. Populations have become today far more mobile than they were ever before, and this mobility has, in turn, led to repeated and fresh contacts so conducive to the development of a people. In other countries, having relatively more extensive coast-lines or navigable rivers, the boat and the steamship have played no mean part in contributing to such contacts, appraisement and appreciation of one another's culture. But in our own vast sub-continent of three hundred and fifty million people our railroads and highways constitute the only means of communication between our wide-spread population. Even among these two, I am sure, comparative statistics, if such were collected, would show that the number of people travelling by the road is far greater than those using the railway. It is because of this increasing mobility

leading to the ushering in of a new era that I regard the road problem as one of intrinsic importance.

The part played by roads in the economic development of a country hardly needs to be emphasized. India is predominantly an agricultural country and trunk roads spanning its length and breadth and feeder roads interlacing the districts and providing an outlet for the produce of the villages in the interior are factors of inestimable economic value. The country where, I believe, somewhat similar conditions prevail is the United States of America, and, you are no doubt aware that a good portion of the States' taxes are spent there on the construction and upkeep of roads. From the East to the West, a distance of more than 3,000 miles, there are not one but several cement-concrete highways traversing that great continent. If, or I should rather say, when, such development takes place in our own country, these Dominions, situated as they are in the very centre of the Indian Peninsula, will become the meeting-place of highways running from the North to the South and from the Eastern to the Western Coast. But in that not far distant future, no less than at present, owing to the rapid development of air transport, these roads will mainly be used for the transport of agricultural produce. If, therefore, this our major industry is to contribute effectively to the supply of our primary needs, the interest as well as convenience of the agriculturist himself must specially be borne in mind in formulating any new plans or programme of Road Construction in India.

The necessity for the expansion of roads in India brings in its train a number of problems pertaining to finance and the technique of road construction. Roads are not only expensive to construct but they involve a large recurring expenditure by way of maintenance. If, therefore, our limited resources are to yield the maximum benefit, it is obvious that thoughtful consideration will have to be bestowed on the framing of a plan which will not only be based on the needs of the present but will also make provision for those of the future. It is due to the absence of such planning in the past that, in several parts of the country, trade and travel have come to adopt routes which have sprung up perhaps fortuitously in the course of time but do not quite fit into the framework of modern agricultural or cammercial development. The waste involved in such haphazard transit is enormous and lays a heavy and unnecessary burden on the State exchequer.

The formulation of a policy based on careful survey and research is necessary for ascertaining the exact kind of roads required in different regions. The volume of traffic on the outskirts of a busy market town varies considerably from that to be found in sparsely populated and undeveloped areas. Between these two extremes, there is a vast range of variation in local problems, each of which requires a different treatment.

For example, motor vehicles have come more into vogue in some places than in others. In certain provinces, there is already a decrease in the number of carts employed for the transport of agricultural produce owing to the motor traffic having taken their place. In others, statistics show that, since agriculture even in the interior has changed its nature from serving a purely local demand to catering for an international market, the number of bullock carts has, owing to the absence of motor vehicles, increased considerably. Evidently, this stage of transition during which our roads will have to meet the demands both of bullock carts and motor traffic will last for some time and it is necessary that we devote considerable

attention to the evolving of methods which will give us roads that will serve this dual purpose.

Similarly, a good deal of emphasis must be laid on the necessity for the reconstruction of existing roads simultaneously with the construction of new ones. Roads must be planned both in alignment and outlay to satisfy the most advanced considerations of technique, combined with maximum facility and safety to the road user. The economic loss that results from improper highway design or construction or from the retention of highways unsuited to the traffic conditions of the present day is still another factor to be guarded against. In short, roads and their construction and maintenance should form an integral part of our national economy; and the network of highways and feeder lines should be so planned that in the long run these arteries of communication come to function as indispensable parts in the body-politic. It need hardly be emphasised that upon the adequacy of communications depends the richness and fulness of our economic, cultural and national life.

The Indian Roads Congress has, in spite of its very recent origin, already given impetus to the consideration of these different questions relating to the construction and maintenance of roads and bridges, and will, I am sure, play an increasingly useful part in the development of communications throughout India.

Gentlemen, it is with the greatest pleasure that I declare open the fourth session of the Indian Roads Congress and wish you every success in your deliberations—(*Cheers*).

Mr. S. G. Stubbs, O.B.E., I.S.L., President of the Congress, then delivered his presidential address. He said:

On behalf of the Indian Roads Congress I accord a hearty welcome to you, the Honourable Raja Shamraj Rajwant Bahadur, and offer you our thanks for coming here today to open the Fourth Session of the Indian Roads Congress. I also take the opportunity of expressing our appreciation of the hospitality that has been extended to us and the most excellent arrangements that have been made for our comfort and for the inspection of important engineering works, including many miles of concrete roads.

The first three meetings of the Indian Roads Congress were held at Delhi, Bangalore and Lucknow, and all expenses of the meetings were financed from the Reserve with the Government of India in the Central Road Fund. At the last meeting held at Lucknow, the Congress passed a resolution urging the Government of India to recognise the Indian Roads Congress as the authority on all technical matters pertaining to roads and bridges and to finance all future meetings of the Roads Congress from the Reserve. Though a copy of this resolution was forwarded to the Government of India, a complete reply has not yet been received. The Government of India have, however, agreed to meet all expenses connected with the present meeting from the Reserve. Our future, therefore, gentlemen, is very uncertain. Our only alternative is to draw again the attention of the Government of India to the very valuable work that is being done and will be done by the Congress, and to repeat our previous request for getting the finances for our meetings from the Reserve.

Since the introduction of the Central Road Fund about eight years ago and owing to the reduction in the revenues of Provincial Governments and the Indian States there has been a tendency to look upon this Fund as the main source of revenue for purposes of financing road constructions.

The amount available for distribution among Provinces and States from the fund amounts to barely rupees one crore at the present time. For a vast country like India this is a very small sum indeed. It is, therefore, essential that this sum should be made to go as far as possible and that the amount of wasteful expenditure and the repetition of costly mistakes should be reduced to a minimum. This is of the utmost importance. The Roads Congress has already played a very large part in achieving this object by the pooling of knowledge and experience which has come about as a result of our meetings during the past three years. The results obtained so far are very satisfactory indeed. But this is not sufficient. It is necessary to look ahead and to map out our progress and to work on preconceived lines of action. A beginning has already been made in this direction in publishing the Standard Specification and Codes of Practice for Road Bridges in India. This should have the result not only of raising the standard of road bridges in India, but it should also reduce the cost of construction. Apart from this, the design of road bridges will be simplified, and a good deal of time will thus be saved. This is all to the good, and the Bridges Sub-Committee who are responsible for the publication of this valuable book are to be heartily congratulated.

The next important step is to publish a similar booklet on roads. Conditions vary to such an enormous extent in India that the compilation of such a book will present very great difficulties. I think it is generally agreed that a code of practice on roads is very desirable indeed. How we shall tackle it has not been decided. The Technical Sub-Committee of the Congress have discussed this matter at their previous meetings and they have tentatively decided that the best way of dealing with this question is to find out what particular subjects are to be included in the Code of Practice and call upon members of the Roads Congress who are experts in the particular lines to write papers for discussion at the Congress. After discussion in the Congress, the Technical Sub-Committe will prepare a draft of the subjects discussed for incorporation in the Code of Practice. It will take many years before the booklet is completed. In fact, it is probable that the book will never be completed as new subjects will be cropping up every year. However, a beginning would be made on some of the most important subjects, so far as our immediate needs are concerned.

Two of the most important subjects to be dealt with are the specifications for waterbound macadam roads and surface painting, which are very extensively used throughout India for road construction, and maintenance. In this connection, it may be mentioned that the life of surface painting is determined to a very large extent in relation to the quality of aggregates which are used.

In order to establish the relative merits of various aggregates used in various parts of India, a test track is under construction at the Government Test House at Alipore, Calcutta, where a sufficent number of tests have been carried out and the results will be published. This should be of invaluable assistance to road engineers throughout India.

The next important subject is earth roads. Owing to the vast mileages of roads of all classes throughout India and the varying conditions this is a colossal and a difficult problem. These roads, however, are of such great importance that it is essential we should concentrate a good deal more attention on the subject than we have done in the past. The problem is mainly one of soil and the behaviour of soils under varying

climatic and traffic conditions and what should be done to bring about an improvement on earth roads. I am glad to say that a beginning has already been made in this direction. The Government of India has appointed a Soil Physicist to help the Road Engineer and if Provinces make the fullest use of this officer, I feel that great progress may be expected in the matter of earth roads.

Before I conclude I wish to make a brief reference to Mr. K. G. Mitchell, Consulting Engineer to the Government of India (Roads), who is now on leave in England. I am sure that all present here today are sorry that Mr. Mitchell is not with us to guide and help us with his sound advice and genial smile. We all know that Mr. Mitchell is the prime mover not only in starting the Congress, but also in keeping it going and by persuading the Government of India to finance all expenditure in connection with our meetings. We, therefore, owe a great deal of gratitude to Mr. Mitchell.

The Congress then adjourned for a group photograph.

Wednesday, January 5, 1938.

Papers A (I) and (II)

Mr. S. G. Stubbs, (President) : During the discussion on the first group of Papers Mr. W. A. Radice has kindly consented to take the Chair. I have great pleasure in calling upon him to do so.

Mr. W. A. Radice (Chairman) : Mr. President and Gentlemen, in inviting Mr. Wilson to introduce his two papers, I would like to inform the Congress that when I was preparing the draft of the Standard Specification and Codes of Practice for Road Bridges in India, which the Congress adopted last year and caused to be printed, I submitted my draft to the scrutiny and criticism of Mr. Wilson and another young brilliant engineer. These gentlemen went over my draft word for word, made several valuable suggestions, recommended certain omissions and in many cases took pains that the text was in entire consonance with the latest ideas and practice. I was able to accept all their suggestions especially I felt that the specification was intended for the guidance of the younger members of our profession and that therefore the views of younger engineers of established competence should prevail. I think that the members of the Congress will approve of my action in acquainting them with the debt of gratitude we all owe to Mr. Wilson *for his valuable help.*

The following two papers were then taken as read :—

PAPER No. (A) (I).

A METHOD OF CALCULATING THE STABILITY OF BRACED PILE PIERS.

BY

GUTHLAC WILSON, B.SC. (ENG.), ASSOC.M.INST.C E., ASSOC.M.AM.SOC., C.E.

INTRODUCTORY.—In 1926 the author was concerned in the design of a number of bridges, the piers of which consisted of two or four screw cylinders braced together above the water-line. When considering the question of the resistance of the piers to overturning forces, the customary method, neglecting lateral earth pressures, gave obviously absurd results. It was then, following up a suggestion to consider the behaviour of a stick thrust into sand and acted on by lateral forces, that the author developed the following theory, and he has since then amplified it and prepared graphs for the easy solution of problems.

This paper sets forth the theory for braced and unbraced piles acted on by concentrated lateral forces, and for braced piles acted on by a distributed force, such as that due to a current of water; the graphs for the solution of problems are presented; the solution of problems is discussed, and a worked example is given.

BASIS OF THEORY.—It is assumed that the overturning force is resisted largely by the lateral earth pressure, entirely so in the case of an unbraced pile. It is then assumed that the earth near the surface gives way to a depth x such that the earth pressure up to this depth on the pile balances the overturning force. We then have a couple composed of two forces T (the overturning force) with an arm of $h_2 + \frac{2x}{3}$ where h_2 is the height above ground-level at which the overturning force acts. The earth pressure on the pile below the depth x must be distributed in such a way as to constitute a balancing couple.

It is also assumed that the earth resistance on the piles or cylinder increases directly as the depth below the surface, as in Rankine's theory of earth pressures.

In the simplest case, a sheet pile wall of considerable length, driven into a flat piece of ground and subjected to a uniform transverse horizontal force per foot run, the maximum earth resistance per foot run per foot of depth would be:

$$w\left\{\frac{1+\sin\phi}{1-\sin\phi}-\frac{1-\sin\phi}{1+\sin\phi}\right\}$$

where w = the weight of a cubic foot of the soil,
and ϕ = the angle of repose of the soil.

i.e., the difference between the passive and active pressures on the two sides of the wall.

In the case of piles or cylinders of moderate dimensions spaced at normal distances apart, the shearing or arching resistance of the soil cannot be neglected and the maximum earth resistance per foot of depth is greater than:

$$d \times w \left\{ \frac{1+\sin\phi}{1-\sin\phi} - \frac{1-\sin\phi}{1+\sin\phi} \right\}$$

especially in the case of sandy or gravelly soils: here d is the diameter of the pile. The above expression could only represent the maximum earth resistance per foot of pile or cylinder per foot depth if the earth in front of and behind the pile were confined between parallel frictionless vertical planes the distance between which was equal to the diameter of the pile: this is manifestly not the case.

The evaluation of the actual earth resistance is a matter of some difficulty and it is the author's practice to compare the actual maximum load on the earth per foot of pile per foot depth, hereafter to be referred to as K, with $wd\left(\frac{1+\sin\phi}{1-\sin\phi}\right)$, and to take the factor of safety as the latter divided by the former.

CASE 1.—SINGLE UNBRACED PILE.

Referring to Figure 1, let T = Overturning force.

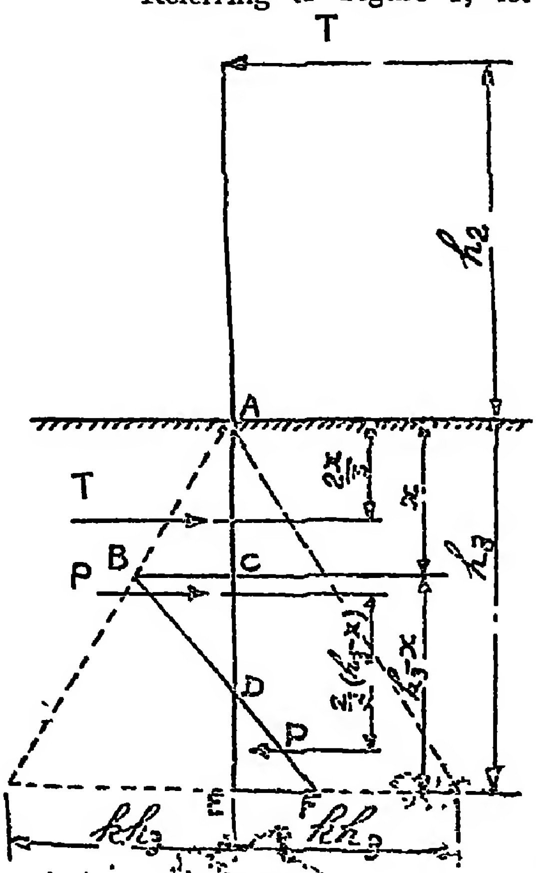


FIGURE 1.

h_3 = Length of pile in ground.

h_2 = Height of line of action of overturning force above ground.

d = Diameter of pile.

w = Weight of earth per cubic foot.

ϕ = Angle of repose.

K = The maximum earth resistance per foot run of pile per foot of depth.

It is assumed that the earth near the surface gives way until a resistance equal to T is set up. This force is represented by the $\triangle$ ABC. The earth pressure on the pile is assumed to be a maximum at this depth x $(=AC)$, and then to diminish and finally undergo a reversal of sign, resulting in two equal and opposite forces P, which are represented by $\triangle$s BCD and DEF. These two forces P, together with the two forces T, maintain the pile in equilibrium.

We have $T = \triangle\, ABC = \frac{1}{2}\, Kx.x = \frac{Kx^2}{2}$

$\therefore \quad x=\sqrt{\frac{2T}{K}}=$ .... (1) and to balance moments

$$P\times\frac{2}{3}(h_3-x)=T\left(h_2+\frac{2x}{3}\right)\text{...} \quad \text{(2)}$$

But $P=\triangle\ BCD=\triangle\ DEF$

$$=\frac{1}{2}Kx(h_3-x)\times\frac{1}{2}=\frac{Kx}{4}(h_3-x)$$

Substituting in (2)

$$\frac{2}{3}\cdot\frac{Kx}{4}(h_3-x)^2=T\left(h_2+\frac{2x}{3}\right)=\frac{Kx^2}{2}\left(h_2+\frac{2x}{3}\right)$$

Hence, $(h_3-x)^2=3x\left(h_2+\frac{2x}{3}\right)$ ....(3)

which may be solved for x. Having found x, $K=2T\div x^2$

It is recommended that this should give a factor of safety of not less than 2·0 compared with $dw\left(\frac{1+\sin\phi}{1-\sin\phi}\right)$: alternatively, assuming a safe value for K, we can solve for h_3.

Bending Moments.—By inspection, the maximum bending moment in the pile is

$$M\ max=T\left(h_2+\frac{2x}{3}\right)\text{....................} (4)$$

CASE II.—TWO PILES RIGIDLY BRACED TOGETHER RESISTING A CONCENTRATED HORIZONTAL LOAD.

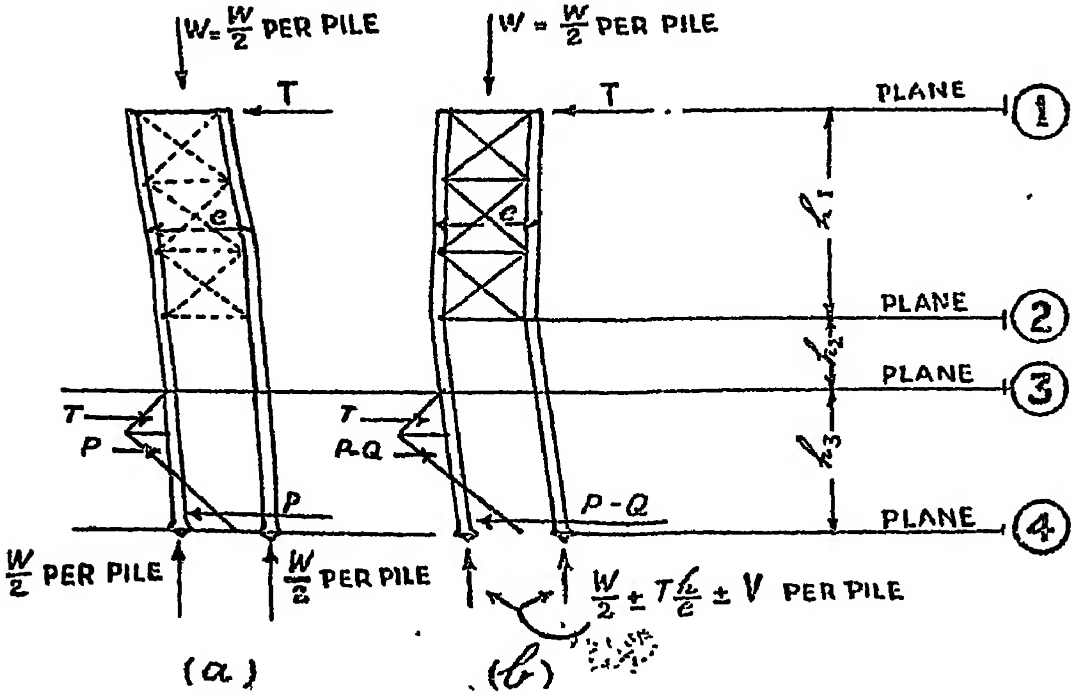


Figure 2.

A comparison of the action of (a), two unbraced piles, and (b), a pair of piles rigidly braced together.

Let h_1 = Height from top of pier to lowest place of bracing.
h_2 = Unbraced length (due to scour, etc.) from bottom of bracings to ground level.
h_3 = Depth into ground below maximum scour.
c = Distance c/c piles in direction of tangential force T.
d = Diameter of piles.
T = Total transverse force on two piles.
W = Total vertical load on two piles.
V = Increase of load on leeward and decrease of load on windward pile due to the fixing moment.
M = Free bending moment at any point, e.g., M_2 = free bending moment at plane (2)
μ = Fixing moment at any point.
$M' = M - \mu$ = resultant bending moment at any point.

It is assumed that the piles are imbedded so far into firm material that the piles are held vertical there, and that the piles in the braced portion of the pier also remain vertical.

The restraint exerted by the bracings on the piles at plane (2) must introduce a fixing moment into them. This moment is assumed to be constant in each pile from plane (2) down to the depth x below ground level: and, being balanced by a lessening (of amount Q) in each of the balancing forces P, then decreases to zero at the bottom of the pile. The fixing moments μ_2 in the piles at plane (2) produce a couple equal to $2\mu_2$ acting on the braced portion of the pier. This must be balanced by an increase of vertical load on the leeward and decrease of loading on the windward piles in addition to the normal one of $T\frac{h_1}{c}$. This increase is equal to V.

$$\text{where } V = \frac{2\,\mu_2}{c} \qquad \text{(5)}$$

There will be secondary stresses in the pier owing to the resultant bending moment at plane (2) which can be evaluated if the dimensions of the members of the pier and the value of μ_2 are known: these stresses do not affect the present argument. Now refer to figure 3 and consider the moments and forces causing the flexure of one pile.

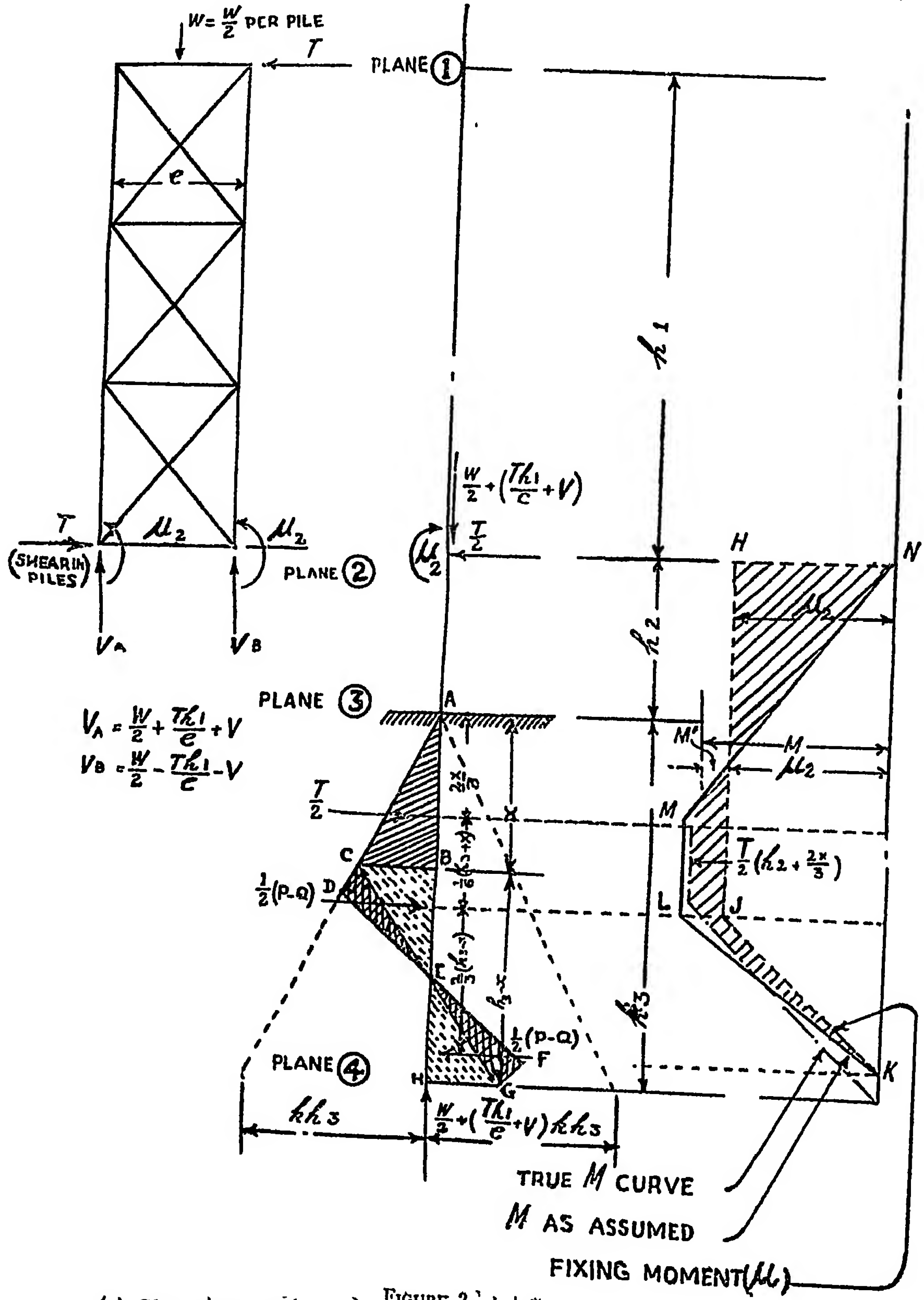


FIGURE 3.

(a) Shows the braced portion and forces acting on it separately.
(b) Shows the forces acting on one pile.
(c) Is the bending moment diagram for one pile.

Note.—The fixing moments above plane (2) have been omitted as these are secondary stresses and depend on the form and dimensions of the structure.

Consider the equilibrium of one pile :

$$\frac{T}{2} = \triangle\ ABC = \frac{1}{2} K x^2$$

$$\therefore\ x = \sqrt{\frac{T}{K}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Let $\frac{P}{2}$ = Area $BCDE$ = Area $EFGH$.

$$\frac{Q}{2} = \text{Area } DCE = \text{Area } EFG$$

$$\therefore\ \frac{1}{2}(P-Q) = \text{Area } BCE = \text{Area } EGH \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$\text{and } \mu_2 = \frac{Q}{2} \times \frac{2}{3}(h_3 - x) = \frac{Q}{3}(h_3 - x) \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

By Moments.

$$\frac{P}{2} \cdot \frac{2}{3}(h_3 - x) - \frac{Q}{2} \cdot \frac{2}{3}(h_3 - x) = \frac{T}{2}\left(h_2 + \frac{2x}{3}\right) - \mu_2$$

$$\therefore\ \frac{P}{3}(h_3 - x) = \frac{T}{2}\left(h_2 + \frac{2x}{3}\right)$$

$$\therefore\ P = \frac{3T}{2(h_3 - x)}\left(h_2 + \frac{2x}{3}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

As the change in inclination from plane (4) to plane (2) is zero, the area of the bending moment diagram between these levels, divided by *E. I.* must also be zero.

It will be sufficiently accurate to approximate by considering the bending moment diagram resulting from the resultant pressures acting at their centres of pressure. The correct form of the diagram has been sketched in Figure 3 (C) and it will be seen that the difference in area is likely to be small.

$$\text{Area } HJKLMN \times \frac{1}{EI} = O.$$

$$\text{i.e. } \frac{\mu_2}{EI}\left\{h_2 + \frac{2x}{3} + \frac{1}{6}(h_3 + x) + \frac{1}{2} \cdot \frac{2}{3}(h_3 - x)\right\}$$

$$= \frac{1}{EI}\left[\frac{T}{2}\left(h_2 + \frac{2x}{3}\right)\left\{\frac{1}{6}(h_3 + x) + \frac{1}{2} \cdot \frac{2}{3}(h_3 - x)\right\}\right.$$

$$\left. + \frac{1}{2}\left\{\frac{T}{2}\left(h_2 + \frac{2x}{3}\right)\left(h_2 + \frac{2x}{3}\right)\right\}\right]$$

$$\therefore\ \frac{\mu_2}{EI}\left(h_2 + \frac{h_3 + x}{2}\right) = \frac{T}{2EI}\left[\left(h_2 + \frac{2x}{3}\right)\left(\frac{h_3}{2} - \frac{x}{6}\right)\right.$$

$$\left. + \left(\frac{h_2}{2} + \frac{x}{3}\right)\left(h_2 + \frac{2x}{3}\right)\right] = O \quad \ldots\ldots (10)$$

$$\therefore\ \mu_2 = \frac{T}{2}\left\{\frac{\left(h_2 + \frac{2x}{3}\right)\left(\frac{h_2}{2} + \frac{h_3}{2} + \frac{x}{6}\right)}{h_2 + \frac{h_3}{2} + \frac{x}{2}}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

From (7), $\frac{1}{2}(P - Q) = \frac{1}{4} Kx\,(h_3 - x)$

$$P - Q = \frac{1}{2} Kx\,(h_3 - x)$$

$\therefore$ Substituting for P and Q from (8) and (9)

$$\frac{1}{2}Kx\,(h_3-x)=\frac{3T}{2(h_3-x)}\left\{\left(h_2+\frac{2x}{3}\right)-\frac{2\mu_2}{T}\right\}$$

$$\therefore\ \frac{1}{3}Kx(h_3-x)^2=T\left[\left(h_2+\frac{2x}{3}\right)-\left\{\frac{\left(h_2+\frac{2x}{3}\right)+\left(\frac{h_2}{2}+\frac{h_3}{2}+\frac{x}{6}\right)}{h_2+\frac{1}{2}\left(h_3+x\right)}\right\}\right]$$

from (6), $T=Kx^2$ ....(12)

$$\text{Hence}\quad \frac{(h_3-x)^2}{3x}=\left[h_2+\frac{2x}{3}-\left\{\frac{\left(h_2+\frac{2x}{3}\right)\left(\frac{h_2}{2}+\frac{h_3}{2}+\frac{x}{6}\right)}{h_2+\frac{1}{2}\left(h_3+x\right)}\right\}\right]\qquad(13)$$

and putting $\frac{x}{h_3}=y$

$$\left\{y^2-1+y\left(2+3\frac{h_2}{h_3}\right)\right\}\left(10\frac{h_2}{h_3}+5+5y\right)$$

$$=15\frac{h_2}{h_3}\left(1+\frac{h_2}{h_3}\right)y+10\left(1+\frac{3h_2}{2h_3}\right)y^2+10\frac{y^3}{3}\qquad\text{......................(14)}$$

Bending Moments.—The maximum bending moment is, by inspection, either

$$\mu_2 \text{ or } \frac{T}{2}\left(h_2+\frac{2x}{3}\right)-\mu_2$$

CASE III.—TWO PILES RIGIDLY BRACED, RESISTING A UNIFORM LOAD ON h_1 AND h_2.

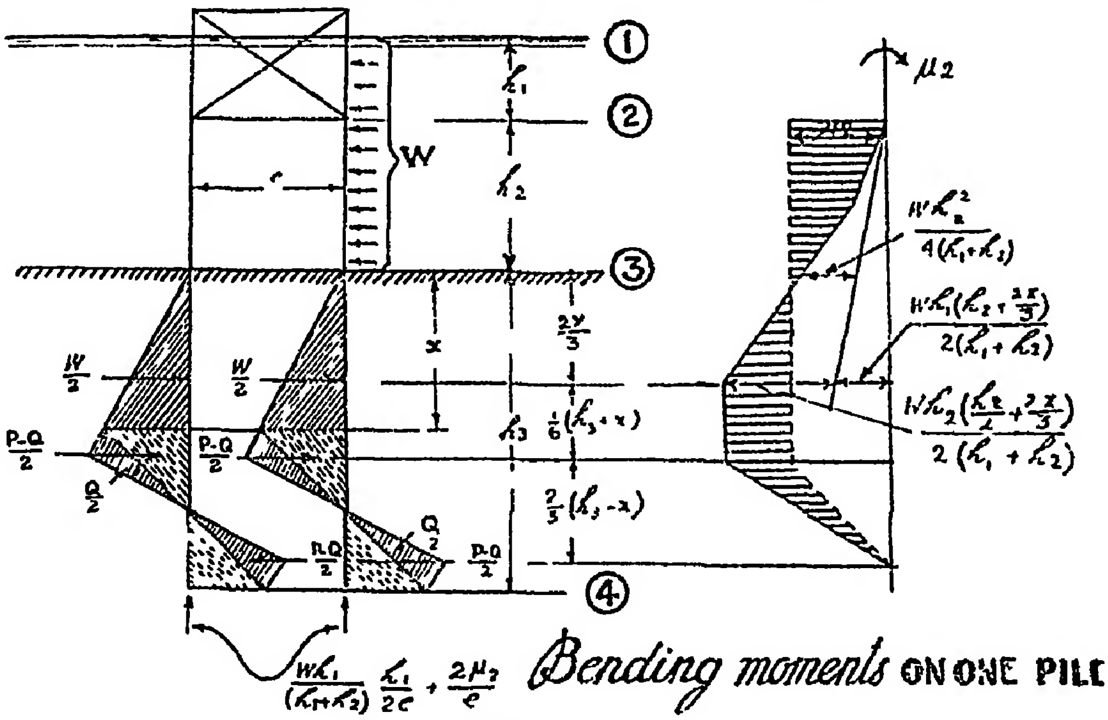


FIGURE 4

Referring to Figure 4, it will be seen that as the slope at plane (2) = slope at plane (4) = zero, total area of bending moment diagram = zero.

$$\frac{h_2}{3}\cdot\frac{wh_2^2}{4(h_1+h_2)}+\frac{1}{2}\cdot\frac{2x}{3}\left\{\frac{Wh_2^2}{4(h_1+h_2)}+\frac{Wh_2\left(\frac{h_2}{2}+\frac{2x}{3}\right)}{2(h_1+h_2)}\right\}+\frac{1}{2}\left(h_2+\frac{2x}{3}\right)\frac{Wh_1\left(h_2+\frac{2x}{3}\right)}{2(h_1+h_2)}$$

$$+\left\{\frac{1}{6}(h_3+x)+\frac{1}{3}(h_3-x)\right\}\left\{\frac{Wh_1\left(h_2+\frac{2x}{3}\right)}{2(h_1+h_2)}+\frac{Wh_2\left(\frac{h_2}{2}+\frac{2x}{3}\right)}{2(h_1+h_2)}\right\}$$

$$=\mu_2\left\{h_2+\frac{2x}{3}+\frac{1}{6}(h_3+x)+\frac{1}{2}\cdot\frac{2}{3}(h_3-x)\right\}\ \ldots\ldots\ldots\ldots(15)$$

$$2x\cdot Kx\cdot\frac{1}{2}=w=Kx^2$$

$$\therefore\ x=\sqrt{\frac{W}{K}}\ \ldots\ldots\ldots\ldots(16)$$

$$2\mu_2=\frac{2Q}{2}\cdot\frac{2}{3}(h_3-x)$$

$$\therefore\ \mu_2=\frac{Q}{3}(h_3-x)\ \ldots\ldots\ldots\ldots(17)$$

Also, $\frac{1}{2}(P-Q)=\frac{1}{2}Kx\,\frac{1}{2}(h_3-x)$

$$P-Q=\frac{Kx}{2}(h_3-x)\ \ldots\ldots\ldots\ldots(18)$$

Consider moments on one pile, taking moments about plane (2)

$$\frac{P-Q}{2}\cdot\tfrac{2}{3}(h_3-x)-\frac{W}{2}\left(h_2+\frac{2x}{3}\right)+\frac{Wh_2}{2(h_1+h_2)}\times\frac{h_2}{2}+\mu_2=0 \quad \ldots(19)$$

but $\mu_2=\dfrac{Q}{3}(h_3-x)$

$$\therefore\quad \frac{P}{3}(h_3-x)-\frac{W}{2}\left(h_2+\frac{2x}{3}\right)+\frac{Wh_2^2}{4(h_1+h_2)}=0 \quad \ldots\ldots(20)$$

Substituting (16) in (18)

$$Q=P-\frac{Kdx}{2}(h_3-x)=P-\frac{W}{2x}(h_3-x) \quad \ldots\ldots(21)$$

From (17) and (21)

$$\mu_2=\frac{Q}{3}\cdot(h_3-x)=\left\{\frac{P}{3}-\frac{W}{6x}(h_1-x)\right\}(h_3-x)$$

$$=\frac{P}{3}(h_3-x)-\frac{W}{6x}(h_3-x)^2 \quad \ldots\ldots(22)$$

From (20) and (22)

$$\mu_2=\frac{W}{2}\cdot\left(h_2+\frac{2x}{3}\right)-\frac{Wh_2^2}{4(h_1+h_2)}-\frac{W}{6x}(h_3-x)^2 \quad \ldots\ldots(23)$$

From (15) and (23)

$$\frac{W}{h_1+h_2}\left[\frac{h_2^3}{12}+\frac{x}{3}\left\{\frac{h_2^2}{4}+\frac{h_2\left(\frac{h_2}{2}+\frac{2x}{3}\right)}{2}\right\}+\frac{h_1\left(h_2+\frac{2x}{3}\right)^2}{4}\right.$$

$$\left.+\left\{\tfrac{1}{6}(h_3+x)+\tfrac{1}{3}(h_3-x)\right\}\left\{\frac{h_1\left(h_2+\frac{2x}{3}\right)}{2}+\frac{h_2\left(\frac{h_2}{2}+\frac{2x}{3}\right)}{2}\right\}\right]$$

$$=W\left\{\tfrac{1}{2}\left(h_2+\frac{2x}{3}\right)-\frac{h_2^2}{4(h_1+h_2)}-\frac{(h_3-x)^2}{6x}\right\}\left\{h_2+\frac{2x}{3}+\frac{h_3+x}{6}+\frac{h_3-x}{3}\right\}$$

Hence

$$3h_2^3x=(h_1+h_2)\left\{9h_2^2x+6h_2x^2+x^3-6h_2h_3^2+12h_2h_3x+3h_3^2x+3h_3x^2-3h_3^3\right\}$$

Putting $\dfrac{x}{h_3}=v$

$$3v\left(\frac{h_2}{h_3}\right)^2\frac{h_2}{h_1+h_2}=v^3+3v^2\left(2\frac{h_2}{h_3}+1\right)+3v\left\{3\left(\frac{h_2}{h_3}\right)^2+4\frac{h_2}{h_3}+1\right\}$$

$$-3\left(2\frac{h_2}{h_3}+1\right) \quad \ldots\ldots(24)$$

STABILITY.—Graphical solutions of equations (3), (14) and (24) giving the value of $x\div h_3$ for various cases, are given on Plates Nos. 1 and 3.

BENDING MOMENTS.—Plate No. 2 gives the position of the point of contrari-flexure for various values of [illegible] and [illegible] in the case of braced piers

resisting a horizontal concentrated load: the maximum bending moment is then $\frac{T}{2} \times mh_2$ or $\frac{T}{2}(h_2+nh_3)$

RECOMMENDED PRACTICE FOR DESIGN OF PIERS.—Assume the diameter of the pile and dimensions of the pier, calculate

(1) The factor of safety against overturning which may be taken as $wd\left(\frac{1+sin\phi}{1-sin\phi}\right) \div K$

(2) The maximum bending moment in the pile

(3) The maximum load on the screws

The horizontal load should be split up in the following manner:

A. Forces transverse to the bridge

(1) Wind on span and live load acting at the level of the pin of the span bearing.

(2) Wind on pier.

(3) Current on pier.

B. Longitudinal forces.

We thus get a longitudinal and a transverse force (T and L_1) acting in plane (1)—this being bearing pin level, if each pile carries a bearing directly—and transverse distributed forces W_1 and W_2.

Find x for each case.

Find K for each case $\left(=\frac{T}{x^2}\right)$

Add together all K's for transverse forces (getting Kt) and obtain the resultant $K=\sqrt{Kt^2 \& Kl^2}$, where Kl is the K for longitudinal forces.

Compare this with $dw\left(\frac{1+sin\theta}{1-sin\theta}\right)$ to get the factor of safety, which should not be less than 2·0 preferably 2·5.

For ordinary sand river beds $\theta=30^{\circ}$

and $w\left(\frac{1+sin\theta}{1-sin\theta}\right)=\frac{112}{2240}\left(\frac{1\frac{1}{2}}{\frac{1}{2}}\right)=0\cdot150$

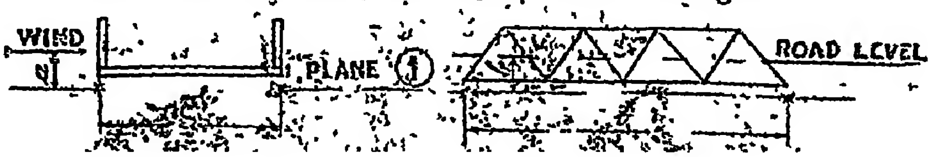
Then calculate the longitudinal and transverse bending moments at plane (2) and add these vectorially. It is not usually necessary to investigate the bending moments at depth x below ground-level, as these will almost always be less than those at plane (2). This may readily be seen by inspection of the situation of the point of contrariflexure, the bending moment will be greater at plane (2) unless mh_2 or h_2+nh_3 is less than h_2+x

Design the pile for the greater of these two resultant bending moments, plus maximum vertical thrust at the plane in question.

LOAD ON SCREW AT BASE OF CYLINDER.

(*a*) Vertical load $=\frac{W}{2}$ per pile.

(*b*) Extra load at bearings due to wind and braking force



Extra load = (wind on span and live load) × $\frac{a}{c}$ + (longitudinal force) × $\frac{b}{l}$

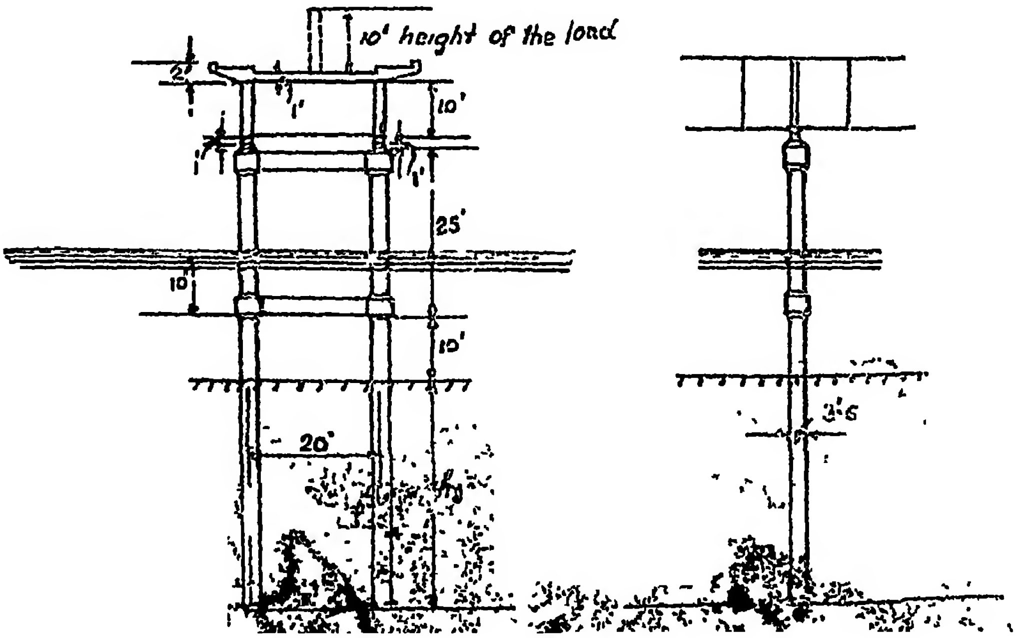
(c) Extra load due to overturning action on pier $= \Sigma \frac{2\mu_2}{c} + \frac{Th_1}{e}$

The safe bearing pressure on the screw should not be exceeded when it is loaded with $\frac{W}{2}$: when the total load due to direct and overturning forces is considered, relief due to skin friction on the pile should be allowed.

Discretion should be used in selecting combinations of loads. When considering live load plus dead load plus maximum wind, current, and longitudinal force, an excess of 25 per cent over normal working stresses should be allowed. This maximum combination of stresses need only be considered in the case of city bridges subjected to heavy traffic, where peak loads occur at regular intervals more or less independent of the weather: in the case of district bridges it is sufficient to consider dead load, with or without live load, and either maximum wind, current, or longitudinal force, whichever gives the worst condition; the pier should be capable of withstanding this combination of loading at normal working stresses.

Worked Example.—Let us consider a bridge pier carrying 250 tons total load, 150 tons dead load plus 100 tons live load, standing 25 feet above normal low water level in a sandy river bed subject to 10 feet of scour below low water level or 20 feet below high water level. Let the maximum wind load on span be 20 tons in the unloaded condition or 12 tons in the loaded condition and let the maximum longitudinal force be 10 tons. The distance between centres of girders may be taken as 20 feet.

We will design a pier consisting of two 3 feet 6 inches diameter screw cylinders to satisfy these conditions for a district bridge.



Assume the layout to be as sketched in Figure 6, screw cylinders 3 feet 6 inches in diameter, consisting of reinforced concrete columns in a thin steel casing, having been selected for practical reasons.

The first step is to select the depth of penetration h_3. This, as we are dealing with a district bridge, depends on the maximum horizontal force: if a combination of horizontal forces had to be considered it would depend on the vectorial sum of these.

The maximum horizontal force is that due to the wind on the unloaded span, 20 tons, unless this is exceeded by that due to the current. The force due to the current may be estimated by the formula given in Waddell's *Bridge Engineering* :—

$$P = K A V^2$$

where P = the force in pounds on the pier

A = the exposed area in square feet

V = the current velocity in feet per second

and K = a constant = 0·62 for circular piers or 1·24 for square piers.

In our case $A = 2 \times 3{\cdot}5 \times 20 = 140$ and we will assume that $V = 10$; $K = 0{\cdot}62$,

$$\therefore P = 0{\cdot}62 \times 140 \times 100 = 8,680 \text{ pounds}$$
$$= 4 \text{ tons, say.}$$

We therefore proceed as follows:—

w for sand = 112 pounds per cubic foot = 0·05 ton

ϕ for sand = 30°

$$\therefore wd\left(\frac{1 + \sin\phi}{1 - \sin\phi}\right) = 0{\cdot}05 \times 3{\cdot}5 \times 3 = 0{\cdot}525$$

Assume a penetration of 35 feet.

Consider first the wind on the unloaded span and refer to Plate No. 1. We have $h_2 \div h_3 = 10 \div 35 = 0{\cdot}286$. Enter the diagram on the bottom margin at $h_2 \div h_3 = 0{\cdot}286$ and run vertically to the upper curve (braced pier), then run horizontally to the left-hand margin, where it is found that

$$y = \frac{x}{h_3} = 0{\cdot}483.$$

Therefore $x = 0{\cdot}483 \times 35 = 16{\cdot}9$ feet

$$K = \frac{T}{x^2} = \frac{20}{16{\cdot}9^2} = 0{\cdot}07$$

$$\text{The factor of safety} = \frac{0{\cdot}525}{0{\cdot}070} = 7{\cdot}50$$

To obtain the maximum bending moment in the pile, refer to Plate No. 2: entering the bottom margin at $h_2 \div h_3 = 0{\cdot}286$, run vertically to the curve and then horizontally to the left-hand margin, where it is found that $nh_3 = 0{\cdot}142 h_3$

$\therefore$ bending moment per pile $= \frac{20}{2}(10 + 0{\cdot}142 \times 35)$

[illegible] $0 \times 14{\cdot}97 = 149{\cdot}7$ foot-tons.

The maxi[illegible] pile by the wind $= (20 \times 11 \div 9$[illegible] $14{\cdot}97 = 50{\cdot}97$ tons.

This, of course, is to be added to the load on the pile due to the dead load from the span and the weight of the pier.

The effects of the wind on the loaded span are twelve-twentieths of those for the unloaded span.

Secondly, check the pier for longitudinal force. The longitudinal force is 10 tons per pier, or 5 tons per pile. Refer to Plate No. 1 and enter at the bottom margin with $h_2 \div h_3 = 35 \div 35 = 1{\cdot}00$ run vertically to the lower curve (unbraced pile) and across to the left-hand margin, where it is found that $x = 0{\cdot}193 \times h_3$.

$$K = \frac{2T}{x^2} = \frac{10}{6{\cdot}75^2} = 0{\cdot}220$$

Factor of safety $= 0{\cdot}525/0{\cdot}220 = 2{\cdot}38$

Maximum bending moment $= 5(h_2 + \tfrac{2}{3}x) = 5(35 + 4{\cdot}5) = 5 \times 39.5 = 197{\cdot}5$ foot-tons.

Finally check the pier for the effects of the current: refer to Plate No 3 and note particularly that here h_1 is the depth from water level to the bottom of the bracings: $h_2 = 10$ and $h_1 + h_2 = 20$, therefore $h_2 \div (h_1 + h_2) = 10 \div 20 = 0{\cdot}5$; $h_2 \div h_3 = 10 \div 35 = 0{\cdot}286$: enter the lower margin at $h_2 \div h_3 = 0\ 286$, run vertically to halfway between the curves for $h_2 \div (h_1 + h_2) = 0{\cdot}4$ and 0 6, then run horizontally to the left hand border, where it is found that $x = 0{\cdot}485h_3$

$$= 0{\cdot}485 \times 35 = 17 \text{ feet}$$

$$K = \frac{T}{x^2} = \frac{4}{17^2} = 0\ 014$$

It is therefore seen that, in this example, the most serious condition is dead load plus live load plus longitudinal force, and the pier should be designed accordingly.

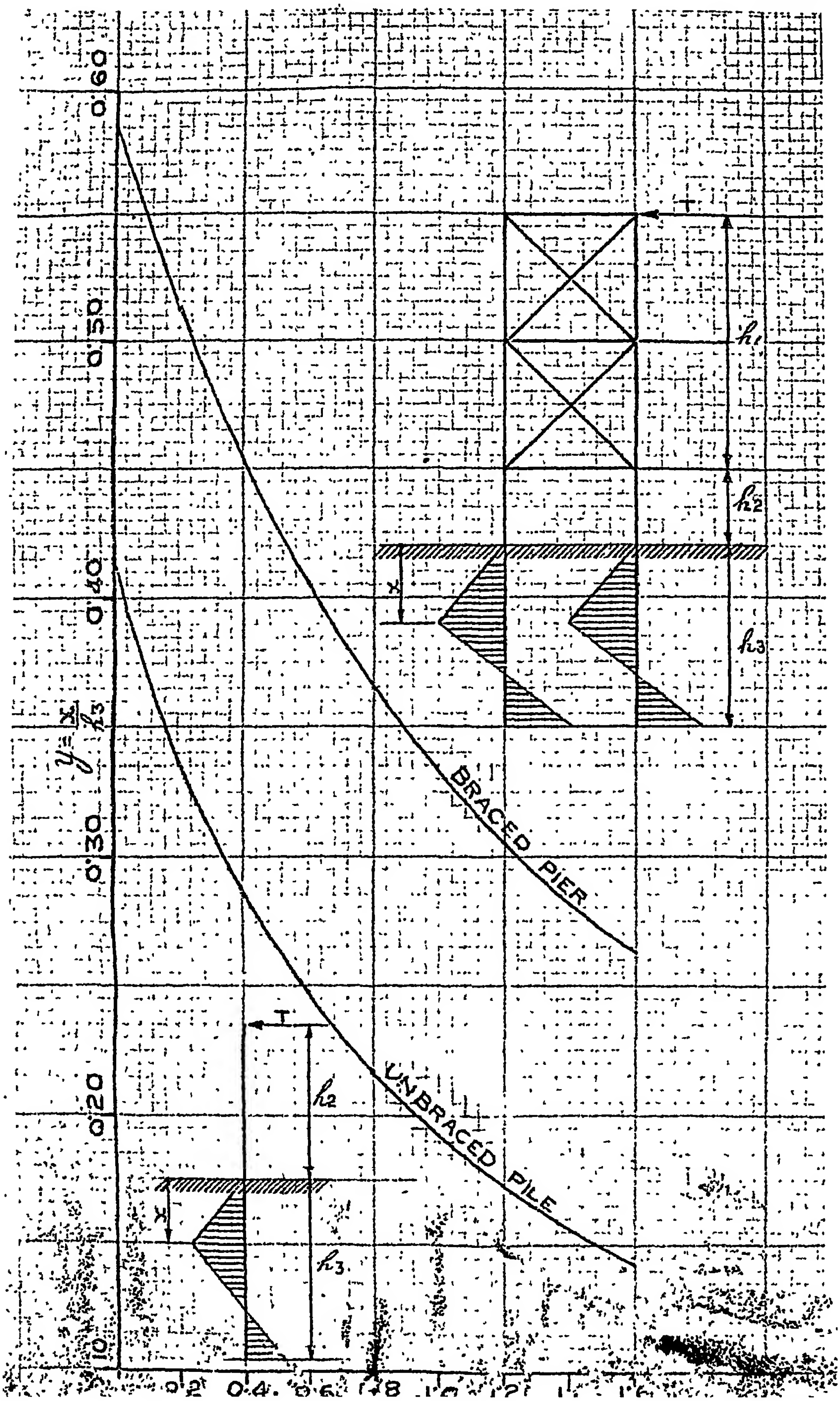
CONCLUSION.—It is believed that the above is a simple and practical method for the design of braced pile or cylinder piers, which, if carefully applied, will result in a stable structure.

It is realized that it is by no means an "exact" method; the problem is really a statically indeterminate one in which the elasticities of the pile and the surrounding soil play an important part.

The author has been working on a more exact theory, which he has not yet been able to produce in a form suitable for practical application, but which indicates that the distribution of earth pressure on the pile or cylinder assumed in the present approximate theory is not grossly erroneous.

Some dozens of bridges on screw pile and screw cylinder foundations have been designed using the methods recommended herein, during the past ten years, and, so far, none of these structures have given any indication that these methods do not supply a reliable and practical solution of the problem.

The reader is further referred to Mr. M. A. Drucker's paper, published independently, after the above method of computation was evolved, in "Civil Engineering" and reprinted in "The [illegible] Concrete Journal" for May 1935. This paper deals [illegible] the stability of telegraph poles, and [illegible] the ground and the line of argument


0·60
0·50
0·40
0·30
0·20
0·10
$y = \frac{x}{h_3}$
BRACED PIER
UNBRACED PILE
T
h_1
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h_3
x
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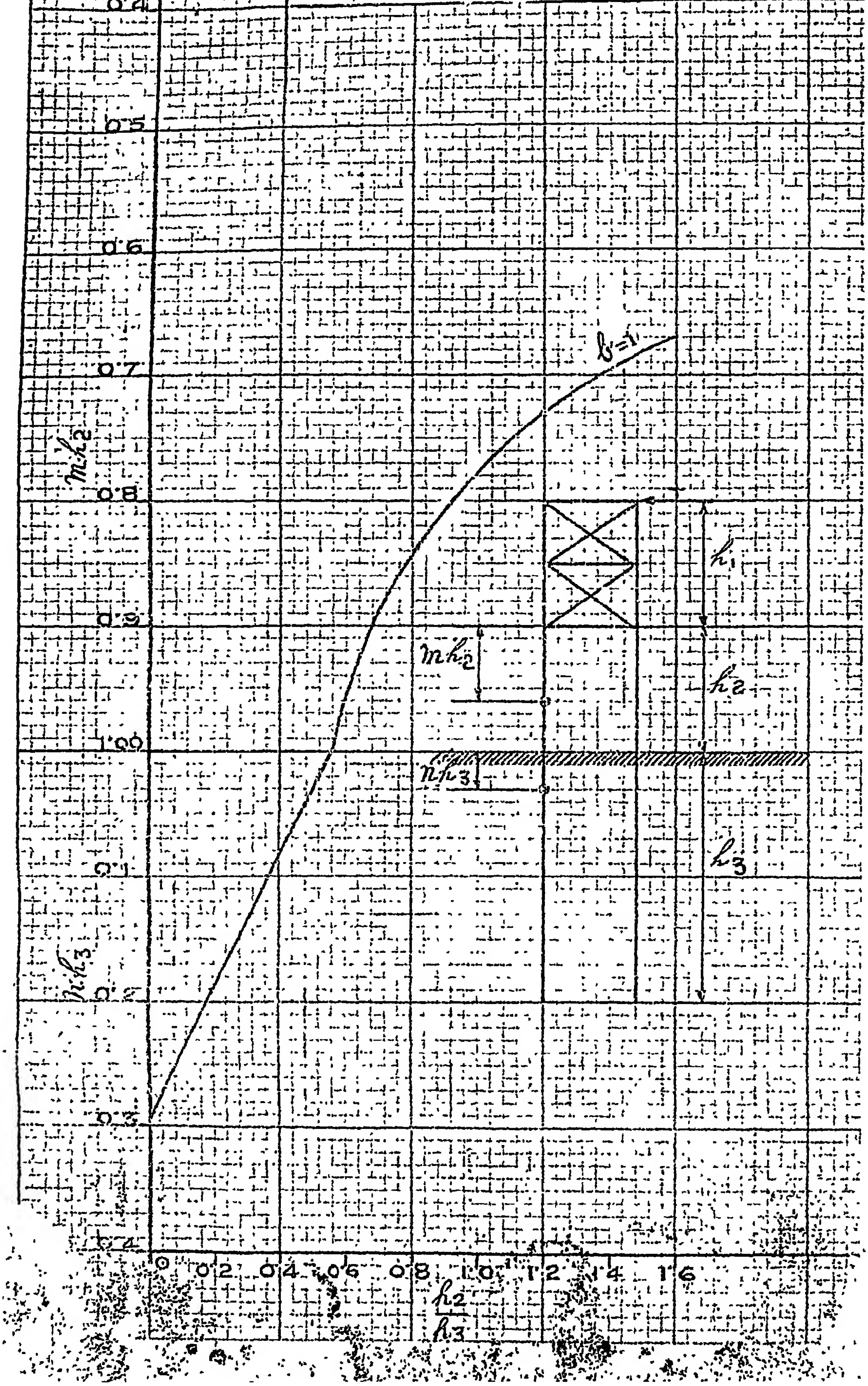
0·4
0·6
0·8
1·0
1·2
1·6

PLATE No. 2.


0·4
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mh'2
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b'=1
mh2
nh3
h1
h2
h3
0 0·2 0·4 0·6 0·8 1·0 1·2 1·4 1·6
h2/h3

PAPER No. (A) (II)

THE DHAKURIA LAKE BRIDGE

BY

GUTHLAC WILSON, B.Sc.(ENG.), ASSOC.M.INST.C.E.,
ASSOC.M.AM.SOC.C.E.

HISTORICAL—The Dhakuria Lakes, which lie to the south of Calcutta, are a series of artificial lakes in a new park area created by the Calcutta Improvement Trust in recent years.

The neighbouring area has very quickly become a popular residential district and "The Lakes" themselves are crowded in the cool of the morning and evening by all classes, who flock there for recuperation and recreation. The only organized sport is rowing. There are four rowing clubs which have club houses on the banks of the lakes and frequent regattas are held.

Until 1935 the developed part of "The Lakes" was the area lying between the line of Lansdowne Road, on the west and Gariahat Road, on the east. About that time the final development of the area extending from west of the Lansdowne Road line nearly to Russa Road south was begun.

Here the excavation for a westerly extension of the main lake was, and is at the time of writing, nearly complete, but divided into sections by a series of bunds and was cut off from the main lake by an isthmus some fifty yards wide, which carried a road.

It was desired that, on completion of the extension of the lake, there should be a bridge at this point of sufficient span to allow two rowing "eights" to pass beneath it simultaneously in safety.

After various designs had been considered, Mr. M. R. Atkins, M.Inst.C.E., the Chief Engineer of the Calcutta Improvement Trust, invited the Braithwaite Burn and Jessop Construction Company to put forward a design, the main requirements of which were that it should be artistic; should have a span of eighty feet, and a clearance of six feet above water level for the central forty feet; and that the road level should be kept as low as possible, as long and high approach banks were considered undesirable.

DESIGN—The design was governed by the following requirements, in addition to those given in the previous paragraph:—

Roadway: 18 feet wide with a 3-inch asphalt surface. Two footpaths to be provided, each 6 feet wide, with a 1-inch asphalt surface.

Loading: A 12-ton steam roller plus 25 per cent impact on the main roadway together with a crowd load of 100 pounds per square foot on the unoccupied area.

84 pounds per square foot on the footpaths.

Before putting the design in hand, two wash borings were made at the site of the bridge, one near each abutment, the results of these are shown on Figure 1. It will be observ[illegible] that the [illegible] consists of silts and clays to a depth of about 72 feet, [illegible] first yellow sand is met.

Such strata can carry heavy vertical loads by means of bearing piles driven to the sand, but are ill adapted to carrying horizontal thrusts amounting to more than a very small percentage of the vertical load.

Under these circumstances the most suitable type of structure appeared to be a cantilever arch: that is a single span cantilever with two anchor arms and two cantilever arms, but no suspended span: the ends of the cantilever arms have a horizontal gap, about an inch wide, between them, so that relative horizontal movement is possible: relative vertical movement is prevented by shear locks.

The foundations consist of five abutment piles and three anchor piles on each side, driven 72 feet to the coarse sand layer.

The general arrangement and cross sections of the bridge are shown in Figure 2.

The bridge consists of five inverted T-beam ribs at 5 feet centres. The anchor arm measures 25 feet from the centre line of the anchorage piles to that of the abutment piles, and the cantilever arm measures 41 feet from the centre line of the abutment piles to the centre of the bridge.

The tables of the T-beams unite to form a continuous soffit to the "arch" in the cantilever arms of the bridge, and to form the floor of a box, which is filled with earth to form a counterweight, in the anchor arms. This counterweight provides only part of the anchorage, the balance of which is provided by tension in the anchor piles.

The stems of the T-beams increase in depth and width and the table increases in thickness as the abutment is approached from either the centre of the bridge or the anchorage.

The overall depth is different for the central, intermediate, and outer ribs. The centre rib is $1\frac{1}{8}$ inches deeper than the intermediate ribs, as additional covering concrete is added to provide the necessary camber in the roadway. The outer ribs are deeper than the others, as they extend into the kerb; this is appropriate as they have to resist a slightly greater bending moment than the others.

The minimum overall depth of the intermediate ribs is 1 foot 8 inches at the centre of the bridge, and their maximum depth is 7 feet at the abutments, after which they again decrease to 3 feet 2 inches at the anchorage. The stem width increases from 6 inches at the centre of the bridge to 20 inches at the abutment and decreases to 8 inches at the anchorage, the thickness of the table varies from $3\frac{1}{2}$ inches to 9 inches in the cantilever arms and from 9 inches to 6 inches in the anchor arms.

The main tensile reinforcement at the top of the T-beam increases from 4 rods $1\frac{1}{4}$-inch diameter at the end of the cantilever arm, to 17 similar rods at the abutment and again decreases to 6 at the anchorage. Tensile reinforcement is also provided at the bottom of the 18 feet nearest the end of each cantilever arm to provide for the reverse bending caused by the support afforded to the end of one cantilever arm by the other, if less heavily loaded, through the shear locks. The shear locks consist of 2-inch diameter steel bars, 18 inches long, sliding in two cast steel pipes of 2-inch internal diameter, one embedded in the concrete on each side. Two such locks are provided for each rib.

In the cantilever portions of the bridge the roadway is carried on a 6-inch thick slab cast integrally with the tops of the main ribs and supported by them and by cross girders at 5-foot centres. The road surface consists of 2 inches thick asphalt bl[illegible]

In the anchor arms the roadway is carried on the fill in the counterweight box. A "dirt wall" over the abutment beam prevents the filling from extending into the cantilever arm.

The footpaths in the main span are carried on cantilever extensions of the main roadway cross girders. In the anchor arms the counterweight box has been made wide enough to carry the footpaths also on the fill.

The bridge is supported at each abutment by five "Franki" piles, one under each rib. The piles are driven to the coarse sand at 72 feet below ground level and carry a maximum load of 125 tons: they are reinforced with eight 1-inch diameter bars and a spiral of $\frac{3}{8}$-inch rod of 6-inch pitch. A 45-inch deep by 24-inch wide beam doubly reinforced is provided to equalize the loading on the piles.

Three Franki piles, driven to the same depth, are provided at each anchorage. These piles have to resist an uplift varying from zero to 35 tons: they are each reinforced with six 1-inch diameter bars and a spiral similar to that in the abutment piles. These piles are situated under the central and outer ribs; the load from the intermediate ribs is carried to the piles by a doubly reinforced beam 11 inches wide by 38 inches deep.

The actual design work was exceedingly simple, the only point calling for comment is the estimation of the load passing across the shear lock: this was determined by the formula usually adopted for the same purpose in the design of double-leaf bascule bridges.

The design stresses were 650 pounds per square inch compression in the concrete and 16,000 pounds per square inch tension in the steel.

CONSTRUCTION OF FOUNDATIONS.—Tenders for the driving of the Franki piles for the foundation were invited in October 1935, and a contract for this work was placed with Messrs. The Braithwaite Burn & Jessop Construction Co., Ltd., on the 24th of the same month.

The pile driving machine was immediately taken to site and erected, and the first pile was driven on the 4th November, 1935. The driving of the whole of the sixteen piles was completed by the 25th November, at the rate of one per working day.

Figure 3 is a photograph showing the work in progress and Figure 4 shows one of the reinforcing cages. The spiral reinforcement is welded to the main reinforcement at each place where they cross one another.

CONSTRUCTION OF SUPERSTRUCTURE.—Tenders for the superstructure were invited in 1936 and the order for this part of the work was placed with Messrs. Associated Engineers Ltd.

Construction which was actually commenced in August, 1936 and finished in February, 1937, was facilitated by the fact that the bridge was constructed on dry land and the waterway excavated afterwards.

The concrete was cast in six stages as follows:—

Stage 1:—The foundations of the wing walls and the abutment beam.

Stage 2:—The middle section of the wing walls, the anchor arm soffit slab and cross girders, and the lower portion of the anchor arm ribs.

Stage 3:—The cantilever soffit slab and the bottom of the cantilever ribs.

Stage 4:—The middle portion of the cantilever ribs and the completion of the anchor arm ribs.

Stage 5 :—The top portion of the cantilever arm ribs together with all cross girders and the main roadway slab.

Stage 6 :—Footpath slabs, railings, wing walls and parapets.

Jharool and pine wood planks, planed, treated with turpentine and whiting and with joints made with strips of tarred felt, were used for the formwork throughout: beams and props were made of *sal* and *jharool* timber.

The centering for the cantilever arm soffit slab is shown in Figure 5. This consisted of transverse rows of *sal bullah* props, cross braced and resting on continuous lines of railway sleepers which rested on prepared ground: each row was placed exactly under a cross girder and carried a transverse beam which supported longitudinal beams, the level of which was adjustable by means of wedges: planks, the upper surface of which conformed to the curvature of the slab, were laid across the longitudinal beams. As the bridge is a cantilever, the centering was struck by releasing the wedges working from the centre line towards the abutments.

An ingenious expedient was adopted when casting the ends of the cantilevers, as the space between them is only 1½ inches wide by 1 foot 8 inches deep and 20 feet long it would have been very difficult to extract timber shuttering. One cantilever was therefore first completed and the end formwork removed. A plaster was then prepared from mud, cow dung, lime and jute fibres and a coat of this, 1½ inches thick, was applied to the end of the finished cantilever and smeared on its free surface with oil. The end of the other cantilever was cast against this and it was later easily removed by the use of an iron rod.

The centering for the hollow chambers inside the cantilever arm was removed through man holes left in the dirt wall over the abutment beam: there was, however, no access to the spaces between the end two pairs of cross girders and the shuttering for these spaces was left in place.

The concrete, which was required by the specification to have a compressive strength of 3,250 pounds per square inch at 28 days, was generally of 1 : 2 : 4 mixture and some specimens, tested at the Alipore Test House, had strengths as high as 6,200 pounds per square inch.

Figure 6 shows the work at approximately Stage 2 and Figures 7 and 8 show the completed bridge.

QUANTITIES AND COSTS.

Substructure.—	16 Franki piles 72 feet long ten reinforced with eight 1-inch diameter bars and six reinforced with six 1-inch diameter bars	Rs. 9,240
Superstructure.—	Concrete—7,990 cubic feet	
	Reinforcing bars—29 tons 18 hundredweights	
	B. R. C. Fabric Nos. 12 and 14—5,743 square feet.	
	Steelwork in shear lock, expansion plates, etc.—15 hundredweights ...	Rs. 24,500
	Total ...	Rs. 33,740

870 cubic feet of plan[illegible] were used for the formwork and 1,070 cubic feet of timber were used f[illegible] [illegible]ops and beams.

The cost per square foot of the elevation area comprised by the road-level and the bottom of the foundations is Rs. 3·21.

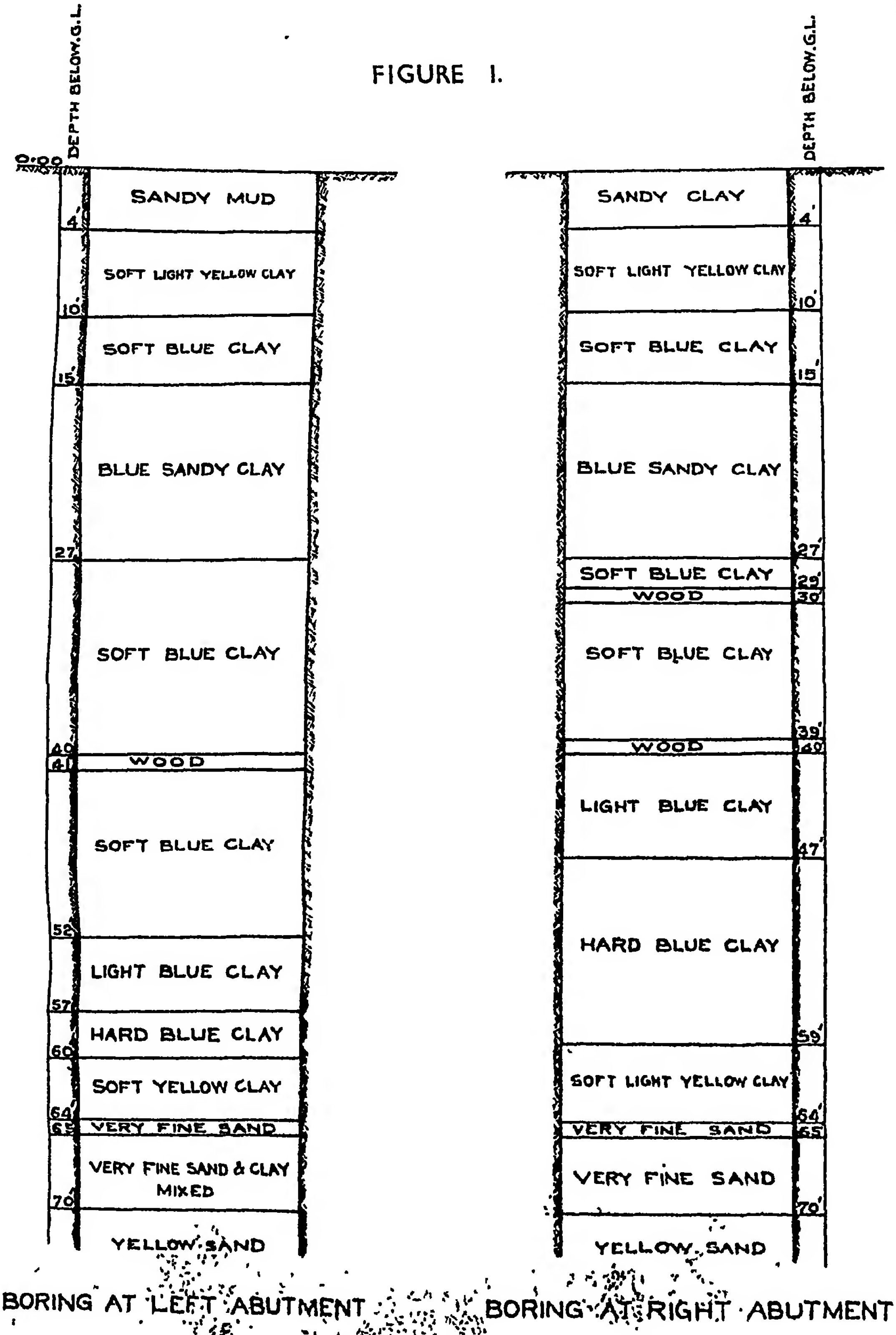
This type of bridge is essentially a single span structure and therefore no attempt has been made to determine the ratio of the cost of the sub-structure to that of those parts of the superstructure which vary with the span.

Conclusion. The Author is indebted to Mr. J. A. Stewart, M.Inst. C.E., Chief Engineer to the Calcutta Improvent Trust, for permission to present this paper..

The bridge was designed by the writer in his capacity of Structural Engineer in The Braithwaite Burn & Jessop Construction Co., Ltd. and the design was checked by the Consulting Engineer to the Calcutta Improvement Trust, Mr. D. H. Remfry, M.Inst.C.E., to whom are due the idea of raising the level of the reinforcement in the exterior ribs and the very neat shear lock detail.

The Author's thanks are also due to Mr. S. K. Roy, B.E., C.E., Managing Director of Messrs. Associated Engineers, Ltd. for having supplied particulars of the erection of the superstructure.

FIGURE I.



DETAIL OF BORINGS — THE DAKURIA LAKE BRIDGE

Discussions on Papers Nos. A (I) and A (II).

Mr. Guthlac Wilson (Author) : I have great pleasure in submitting for discussion my two papers on "A Method of Calculating the Stability of Braced Pile Piers", and "The Dhakuria Lake Bridge."

The subject of the first paper has been a hobby of mine for a long time and I hope that the paper may be of use to other engineers.

I have some photographs of the bridge described in the second paper, which may be of interest and these I will pass round for your inspection. (The photograph will be found on page 24 *a*).

Mr. W. A. Radice (Chairman): Will members kindly open the discussion on the papers presented by Mr. Wilson.

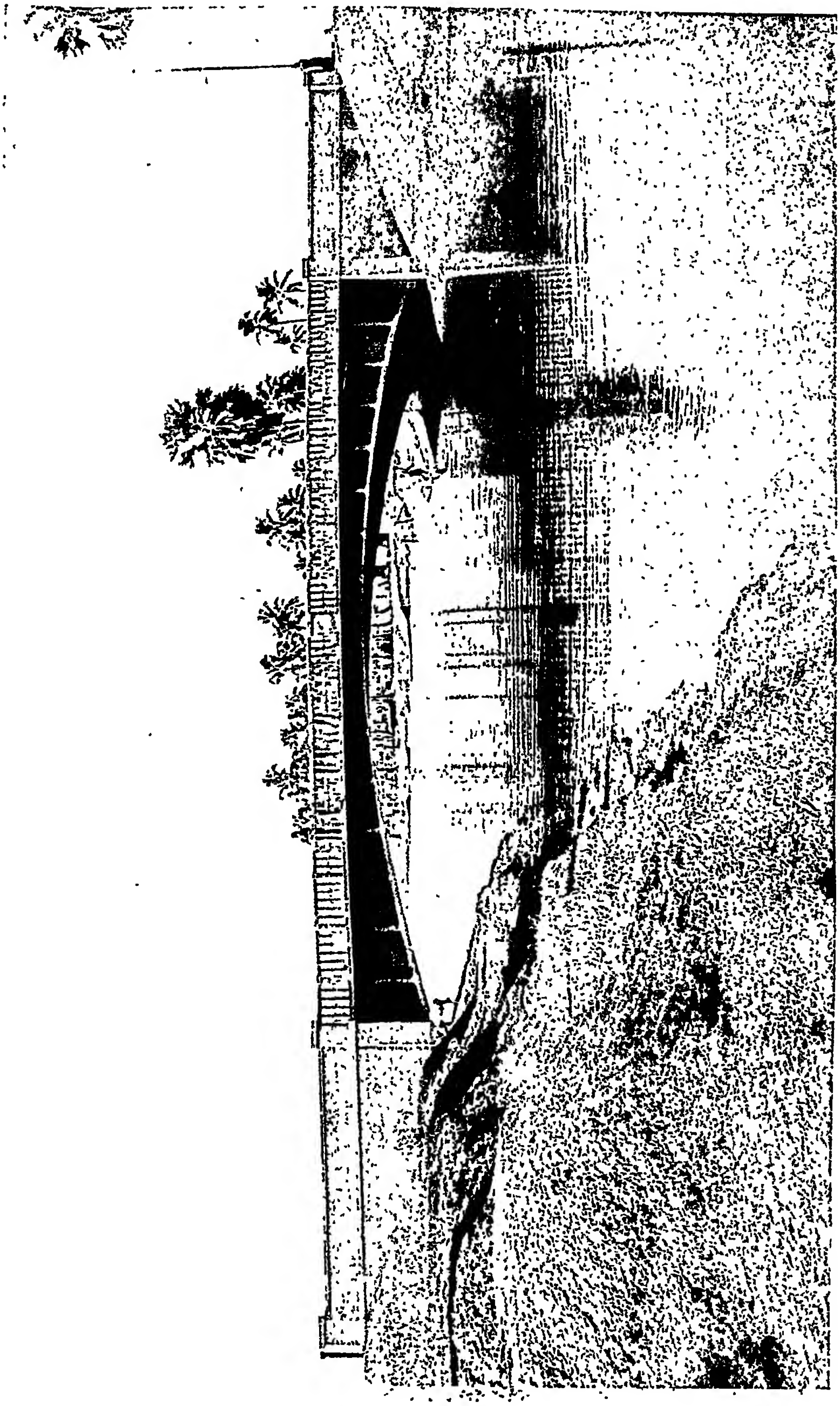
Nawab Ahsan Yar Jung Bahadur (Hyderabad-Deccan) : As we generally understand that hard clay is good for foundations for piles I do not see any reason why we should go down through such clay to yellow sand to a depth of about 70 feet for pile foundations.

Rao Sahib M. A. Rangaswamy (Bihar) : In Bihar I had occasion to construct a screw pile bridge across a river and then I noticed that although we had estimated a certain depth of penetration the screw pile could not go to that depth which we had expected to be able to reach. In this paper the author has worked out a theory to work out the depth of penetration but I find that this will not always hold good in practice. Because if we find that the subsoil strata is not the same as we expected it to be as a result of the test borings the screw cannot go down and the pile will show a tendency to twist. So this theory advanced in the paper may not hold good in all cases.

Mr. W. A. Radice (Chairman): Will Mr. Wilson reply to these points.

Mr. Guthlac Wilson (Author) : With regard to the question put by Nawab Ahsan Yar Jung Bahadur, the piles were carried down to the sand as we find it is always better to found on an incompressible material, such as sand, if such a stratum can be reached by the pile, than on clay, which is compressible.

With regard to the second question it appears to me that the first essential, before commencing the design of a bridge, is to make really reliable borings; I think that answers this question.



The Dhakuria Lake Bridge.

Paper C

Mr. W. A. Radice (Chairman) : I shall call upon Rai Bahadur S. N. Bhaduri to introduce his paper on "Reinforced Cement Concrete Bridges of 24 feet span constructed in Gwalior State."

The following paper was then taken as read :—

PAPER No. (C).

REINFORCED CEMENT CONCRETE BRIDGES OF 24 FEET SPAN CONSTRUCTED IN GWALIOR STATE.

BY

RAI BAHADUR S. N. BHADURI, B.A., C.E., M.I.E.(IND.),
CHIEF ENGINEER, P. W. D., GWALIOR GOVERNMENT.

The importance of roads—for commercial and industrial development of towns, for facility of communication from one place to another and for several indirect advantages that accrue from their construction—has long been realized by Gwalior Durbar.

Years ago a regular road development programme was prepared and the order in which the roads were to be constructed was laid down. Surveys and estimates for these roads were prepared and their construction was taken in hand as funds were made available. As a result of this progressive policy there are at present 2,243 miles of well-maintained metalled road in the State.

In the beginning to keep down cost of construction, Irish Causeways (locally called *Rapats*) across streams, and low level causeways with vents at river crossings were built. The low level causeways and flush *Rapats* served their purpose well enough when traffic was slow. Now that the intensity of traffic has increased and mechanically propelled fast vehicles have replaced the slow moving traffic of yore, it is found that flush *Rapats* and low causeways are no longer suitable for the altered conditions. With the slightest rainfall these *Rapats* and causeways get flooded and obstruct traffic. Moreover, unless the approaches to these are carefully laid out in a catenary curve and are properly maintained, the surfaces become bumpy, especially at the joints of sloping and horizontal portions. To remove these defects and to improve the *Rapats* and causeways, reinforced cement concrete submersible bridges were designed and commenced to be built as far back as 1930. Details of eight bridges so far completed in reinforced cement concrete are given overleaf:—

	24 feet span re-inforced cement concrete sub-mersible bridges.	Situation. Name of road.	Situation. Mile	No. of spans.	Height of piers from Mean Bed Level.	Length between abut-ments.	Year of comple-tion.	Cubical contents of openings from base of foundation to intrados of arches.	Total Cost.	Rate per cubic foot of opening (Col. 10—Col. 9)	Remarks
[illegible]	2	3	4	5	6	7	8	9	10	11	12
					Feet.	Feet.		Cubic feet	Rs.	Re.	
[illegible]	Naraini river	Bhelsa-Pachhar	13rd	9	4½	255	1931	250,125	42,258	0·16	Piers and abutments built in stone.
2	Chambal river	Arnia-Suvasra	29th	30	5½	815	1933	767,970	73,634	0 09	do.
3	Kali Sindh river.	Ujjain-Maksi	9th	6	11	175	1933	214,860	29,909	0 12	do.
4	Chaoli river	Susner-Patan	26th	5	12	136	1936	262,428	51,922	0·19	Piers and abutments built in cement concrete.
5	Betwa river	Bhelsa-Shamsabad.	1st	16	6¼	118	1937	150,528	54,655	0·37	Piers, and abutments built in stone.
6	Beas river	do.	2nd	19	6	584	1937	493,430	78,382	0 16	do.
7	Kalipahari river.	Shivpuri-Jhansi	40th	6	4¼	166	1937	36,792	24,000	0·65	do.
8	Anas river	Rajgarh-Jhabua	2nd	9	12	251	1937	310,527	37,842	0·12	do.

In each case the road surface is made a little higher than the ordinary flood level so that it may be open to traffic during ordinary floods. In high floods the bridge is submerged for a short time for which these floods last. It would have been very expensive to make high-level bridges. By building submersible bridges expenditure is kept down without seriously affecting the usefulness of the roads.

Before adopting the span of 24 feet, sections of a number of crossings were taken and it was found that the depth of ordinary flood seldom exceeded 12 feet and that the highest flood level was very much higher than this. As the economical span of an arch is approximately twice the height of the pier, 24 feet span appeared suitable. Rough estimates for different spans were then prepared and it was found that an arched bridge of 24 feet span was economical and suited a number of crossings. This span was therefore adopted. Three-centered arch is adopted as it is pleasing to the eye, is easily constructed, gives an economical design and is better suited to this kind of construction than a sègmental arch which can seldom be made to fit the line of pressure.

To obtain uniformity of construction, steel centerings were made and carried from place to place as required for construction.

In foundations of almost all bridges, after excavating 4 feet to 7 feet of sandy stuff, rock was met with. This simplified construction to a great extent and enabled open foundation work to be done. Enclosures for excavating piers and abutments were made with gunny bags filled with earth. Water was pumped out by means of pulsometer pumps of 3 inch or 4 inch diameter worked by steam supplied from the boiler of a Road Roller which was taken down to the dry bed of the river and placed in a position from which several pits could be served.

The piers of these submersible bridges were made of coursed rubble stone masonry except in the case of the Chaoli Bridge where owing to the difficulty of obtainig good stone, cement concrete piers were built. Details of construction of the Chaoli Bridge are given below and except for the piers these apply to the other bridges also.

The piers of the Chaoli Bridge were built of cement concrete of proportion 1 cement, 2 sand and 4 stone metal graded from 2 inches to $\frac{1}{4}$ inch size. 15 per cent stone plums were placed in concrete to cheapen the cost. The form for the concrete piers was made of strong wooden frames faced with sixteen *B. W. G.* iron-sheets.

Old rails weighing 14 or 18 pounds per yard were fixed in holes dug in the rocky bottom of foundation pits as detailed below.

One inch diameter steel rod 8 inches long was passed through the web of the rails at the bottom. This end was then placed in holes in rock and concreted. Rails were staggered on plan and they were carried up vertically to skew-back level, where cross-bars were tied on to the top of rails in two lines. Later on, the top and the bottom reinforcement of the arch was tied to these cross-bars. After fixing the rails, the forms for the piers were placed in position.

As the height of the piers of the Chaoli Bridge is only 12 feet above the mean bed level of the river, the whole pier was concreted in one day.

To secure uniform mixing of the ingredients of concrete a Jæger Batch Concrete Mixer having a capacity of 12 cubic feet of unmixed material and working on crude oil was secured for this work. With this machine

one full bag of cement (gross weight 1/20 of a ton, nett capacity 1·2 cubic feet) was used with each batch.

Plate No. II shows the details of centering. For one span five trusses were used; each truss was made in two sections, for facility of transport. These sections were bolted together at the site. Temporary pillars were built in the middle of the span and adjoining the piers on which the trusses were placed. Three small jack-screws were put under each truss—one at each end and the third in the middle. By means of these jack-screws the trusses were brought to one level. All the trusses were braced together both horizontally and diagonally. As soon as the trusses were levelled and braced, pieces of channel iron 2 inches by 1½ inches were laid on them—channel face down—to obtain a smooth surface for placing concrete. To prevent mortars from oozing out through the joints of the channels, thin coir string was caulked into the joints on which puddle earth was pressed and smoothed down. This gave a water-tight surface. String marks were visible in the soffit of the completed arch and if anything relieved the monotony of a plain smooth surface.

Bottom reinforcement of the arch was then placed on 1½ inch cement concrete cubes. This gave a cover of 1½ inches for the bottom reinforcement. For longitudinal reinforcement ½ inch diameter steel rounds were placed 6 inches centre to centre. For cross reinforcement ¼ inch diameter bars were used 12 inches centre to centre. Top reinforcement was placed 1 inch below the extrados of the arch. The bottom and the top reinforcements were held together by means of ½ inch diameter double headed hooks—one for every 25 square feet of arch area. Vertical boards were put along the whole length of the pier for the skew-back. The reinforcements being placed correctly in position and the face plates being fixed in a vertical plane parallel to the centre line of the bridge, by brackets bolted to the trusses, concreting was commenced simultaneously from the two skew-backs and carried evenly towards the crown. The thickness of concrete at the haunches is 18 inches reducing to 12 inches at the crown.

The quantity of concrete required for one arch including the skew-back which was cast along with the arch being 925 cubic feet, there was no difficulty in completing one arch in one day.

Centerings were lowered on the eighth day after concreting an arch. Each of the fifteen Jack-screws in one span were attended to by one man and all were lowered simultaneously, one turn at a time till a clearance of 3 inches was secured for the removal of the channels. Three days after the removal of centering, the face walls were built in coursed rubble masonry in cement mortar (1 cement and 6 sand). Weak cement concrete proportion 1 cemant, 4 sand and 8 metal was then placed on the haunches up to the extrados of the arches. On this 6 inches of cement concrete (proportion 1 : 3 : 6) was laid to take the cement concrete roadway.

The haunches of the Chambal bridge on the Arnia-Suvasra road were filled with well rammed sand and boulders. On this 9 inches thick lime concrete was laid to take the cement concrete roadway. The arches were completed on the 30th June, 1933, and by the 12th July, cement concrete roadway was laid in all but 60 feet length when a 12 foot flood came on the bridge. Except scouring out the lime concrete and rammed sand and boulders in 60 feet length, where cement concrete roadway was not laid, no damage was done to the Chambal bridge. Therefore, in the Chaoli

bridge cement mortar was used for face-wall and weak cement concrete was used for filling haunches to save time as work was being pushed to completion before the break of the monsoon. A couple of days after the haunches were filled, a depth of four feet of water passed over the bridge in an unexpected flood. Owing to cement concrete having been used for filling the haunches, no damage was done.

In all other bridges lime mortar was used in face-wall and lime concrete in filling haunches. An insulating layer of 2 inches of sand was spread on the weak cement concrete and 6 inches thick cement concrete in the proportion of 1 cement, 1½ sand and 3 metal graded from 2 inches to ¼ inch was laid for the roadway. The cement concrete for the road surface was laid in blocks of 25 feet length, the transverse joints being at an angle of 45 degrees to the direction of the flow of the river.

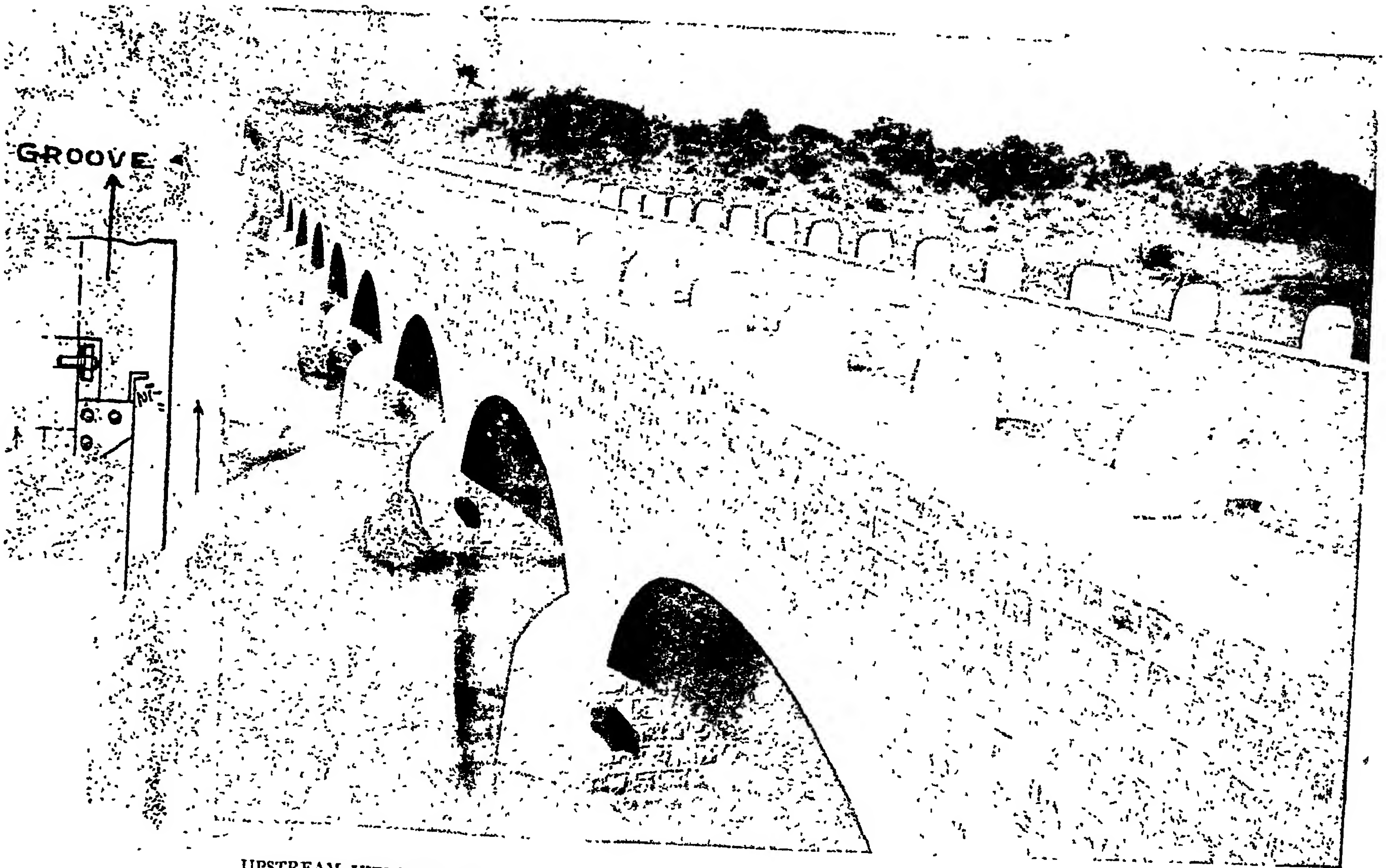
Premoulded expansion joints ½ inch thick composed of Mexphalte and fine sand 5 feet in length and 6 inches in width were placed in position both transversely between adjacent road-blocks and longitudinally between road-blocks and copings up and down-stream of the roadway before putting in the concrete. Expansion joint materials are available in the market under various proprietary names. As they are all expensive the following is a simple and cheap method of making expansion joint sheets adapted from the *Indian Concrete journal*, Vol. IX, No. 8, page 277.

Fine clean sand was heated in a large flat pan to a temperature of 400 degrees fahrenheit. Mexphalte R2 was also heated to the same temperature in a separate pan. 6 seers of sand by weight was then put into 4 seers of Mexphalte and thoroughly incorporated with it and poured into moulds 5 feet by 6 inches by ½ inch which were lined with oiled paper, and were levelled up by striking with a batten painted with soft soap and water to prevent asphalt adhering to it. On cooling the strips of expansion joints were taken out of moulds and stored for use as required.

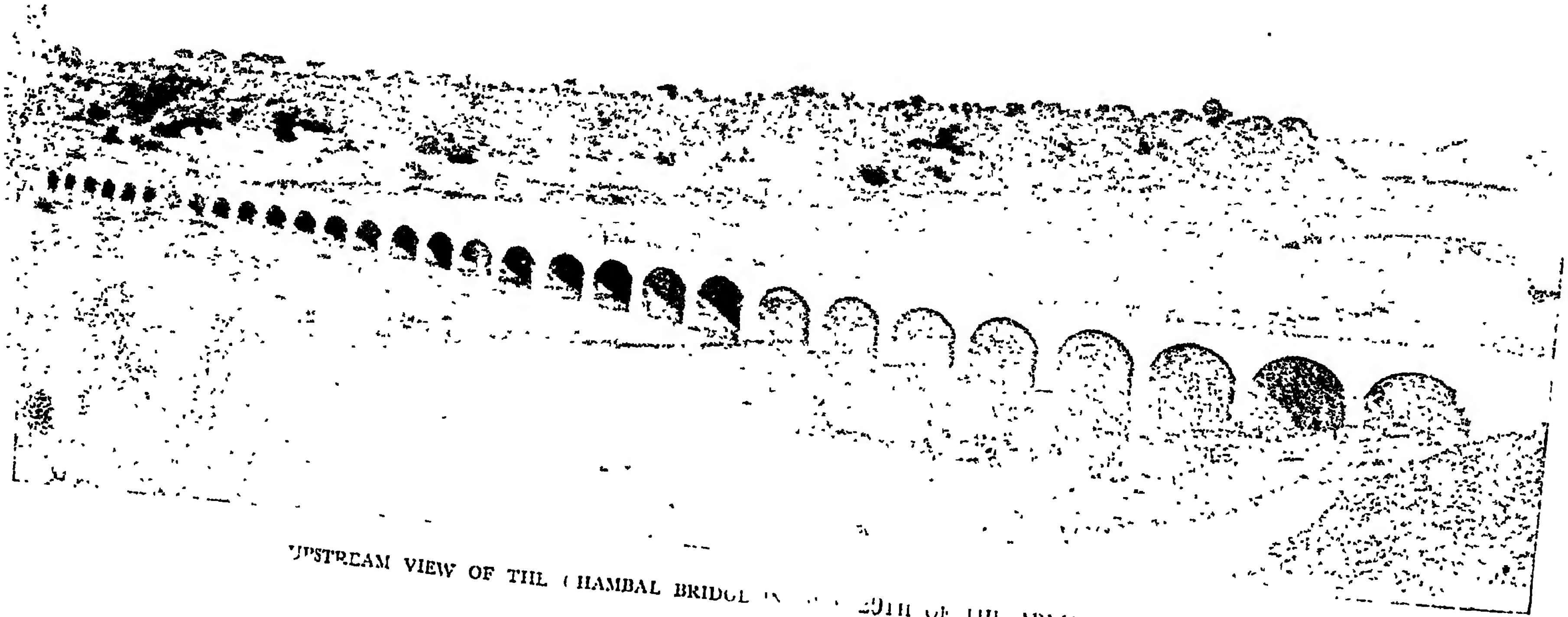
The coping is 18 inches wide and 9 inches thick, grooved to take collapsible railings details of which are shown on Plate No. III. Before laying the concrete of coping, guard-stones were placed between each set of collapsible railing. Guard-stones 2 feet 3 inches long by 18 inches wide by 8 inches thick were precast in reinforced cememt concrete, the bottom 9 inches being left rough. When placed in position 1 foot 6 inches showed above the road surface. The purpose of putting these guard-stones is to indicate the width of the road when the river water is 6 inches to a foot above road surface. As the collapsible railings have to be lowered to rest inside the groove of the coping before rains set in, there is nothing to indicate the width of the roadway, to motorists and others, who may have to use the bridge during low floods.

These bridges are calculated to carry a load of twelve British Engineering Standard Association Units plus 50 per cent allowance for impact.

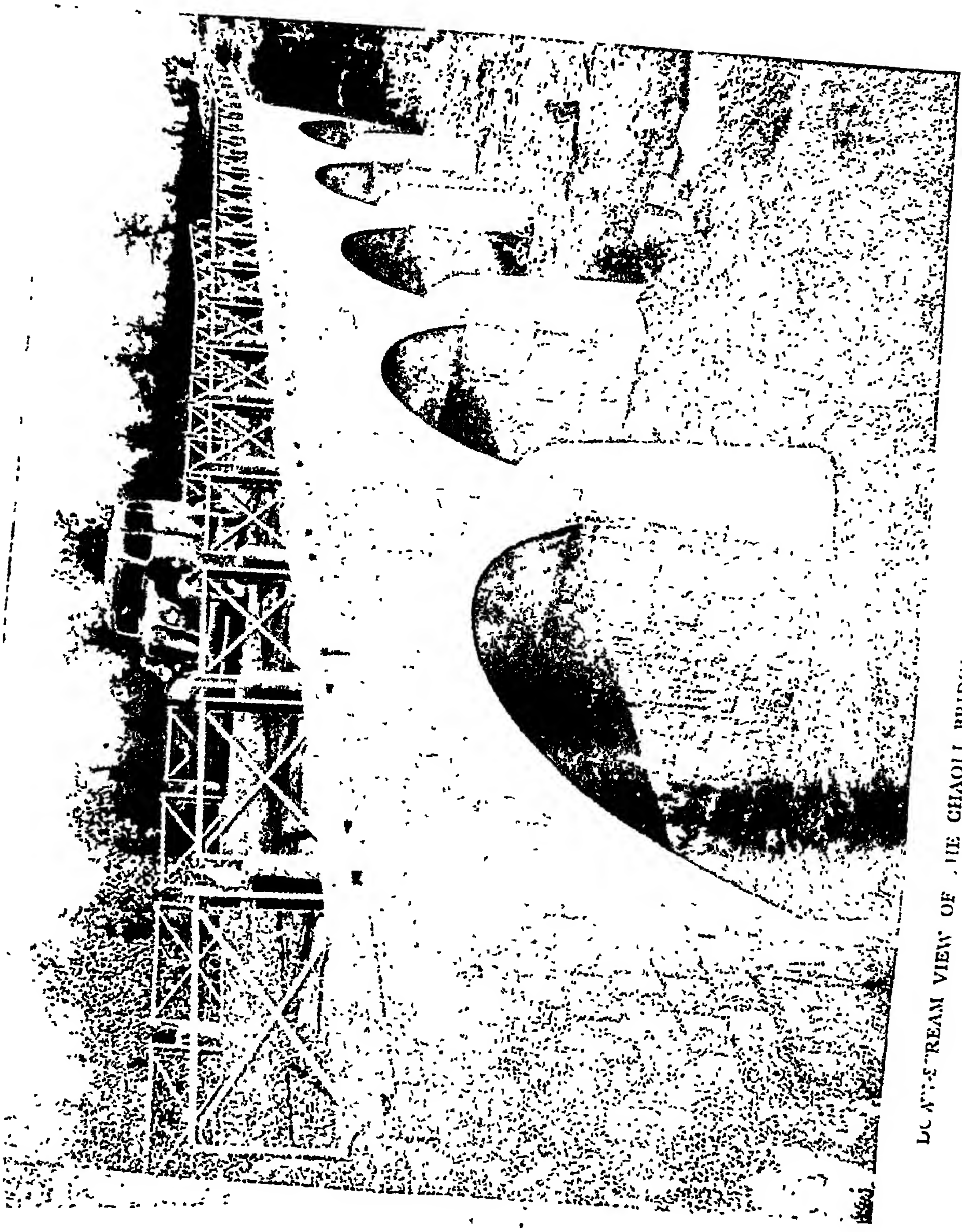
In conclusion it may be mentioned that these submersible bridges have stood the test of floods, which range from 4 to 30 feet, extremely well.



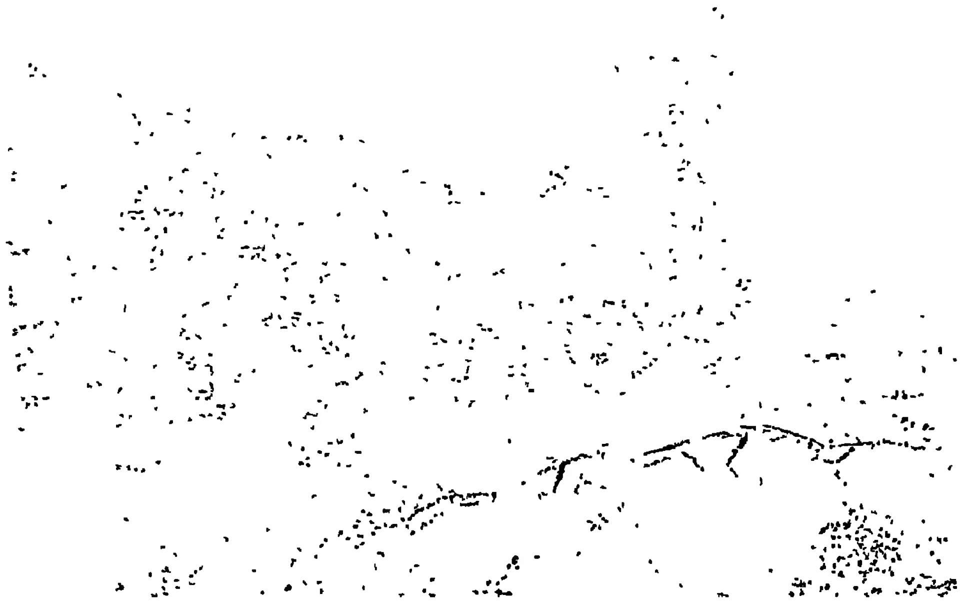
UPSTREAM VIEW OF THE NARAINI BRIDGE FROM BHELSA IN MILE 43RD OF THE BHELSA-PACHHAR ROAD

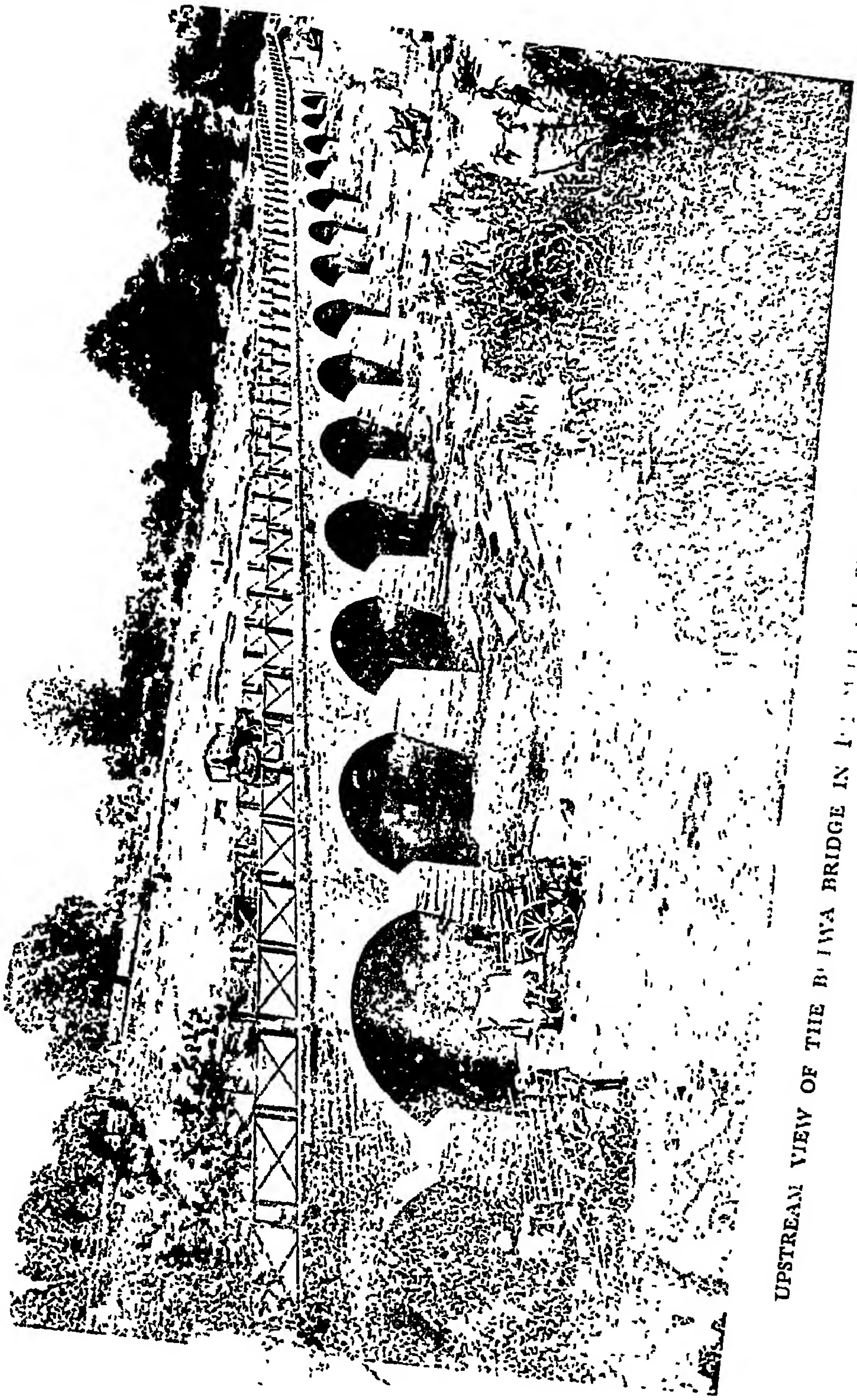


UPSTREAM VIEW OF THE CHAMBAL BRIDGE IN ... 29TH OF THE ARMA-SUVASRA ROAD



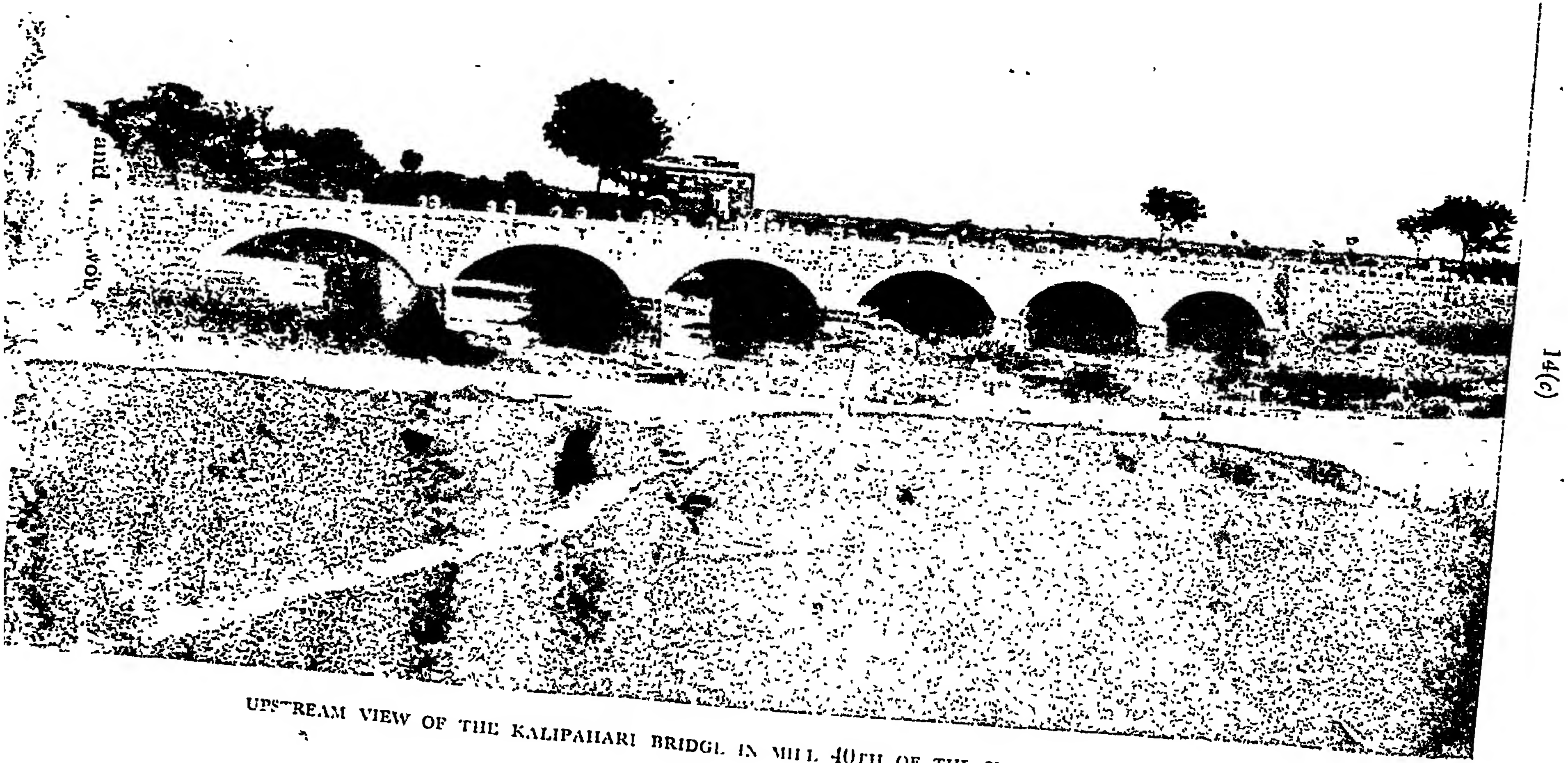
DOWNSTREAM VIEW OF THE CHAOLI BRIDGE [illegible] THE [illegible]SKER-PATAN ROAD





UPSTREAM VIEW OF THE B[illegible]WA BRIDGE IN [illegible] OF THE BHILSA-SHAMSABAD ROAD

DOWN-STREAM VIEW OF THE BEAS BRIDGE IN 2ND MILE OF THE BHELSA-SHAMSABAD ROAD



UPSTREAM VIEW OF THE KALIPAHARI BRIDGE IN MILE 40TH OF THE SHIVPURI-JHANSI ROAD

[illegible] ge, the [illegible]
[illegible] mary dep [illegible]
[illegible] river be [illegible]

Discussions on Paper No. C.

Rai Bahadur S. N. Bhaduri (Author) : In Gwalior there are a number of rivers and nullahs in which during the rainy season, heavy floods occur for a few days only. During the rest of the monsoon period, the depth of water is low and in the remaining months of the year there is hardly any flow of water.

The problem was to build bridges which, without being costly, would allow the road across the rivers to be passable for traffic almost throughout the year, except for periods of high floods.

A solution was found by constructing submersible bridges because high level bridges, on account of their heavy cost, had to be ruled out of consideration.

The Chaoli bridge was built in Cement Concrete as it had to be completed before the rains set in and as stone suitable for masonry was not available within an easy distance of the work.

I shall be pleased to answer any questions that may be put regarding this paper.

Nawab Ahsan Yar Jung Bahadur (Hyderabad State) : Will Rai Bahadur Bhaduri tell us what kind of foundation he met with. In my experience I find that unless foundations are carefully examined and piers are tied together there is danger of failure during heavy floods.

Rai Sahib Fateh Chand (United Province) : I am greatly interested in this paper. In the United Provinces in many places we have heavy rains for only a few days and therefore it is unnecessary to build high-level bridges owing to the greater cost and possible inconvenience due to gradients and approaches. But the question is whether submersible bridges result in real economy. Do they economise in the work of the foundations and in labour charges or only in the cost of materials? What is the minimum economical width and minimum cost?

Mr. Syed Arifuddin (Hyderabad State) : We have been doing this work in Hyderabad and have built several bridges in surki and in lime concrete. The work is rather in an experimental stage but so far they have proved satisfactory. After a few years you may expect a paper from Hyderabad on this subject.

There is a limit to the building of high level causeways. I sometimes find that the estimates for constructing a high-level causeway and a full-height bridge come nearly the same. When the difference in the cost of the two types of structures is not such as to matter, I think, it is not advisable to choose a high-level causeway, or a submersible bridge, in preference to a full-height bridge. It is only when the cost of the high-level causeway is about 50 per cent of the cost of an all-weather bridge that the former should be chosen. Whenever a high-level causeway is constructed we should know what the full-height bridge would have cost. I hope Rai Bahadur Bhaduri will give some figures of relative costs if possible.

Mr. Dildar Hussain (Hyderabad State) : Mr. Arifuddin has taken the wind out of my sails. The height of piers given in the paper varies between 4½ feet and 10 feet. Why should a span of 24 feet be adopted for such pie[illegible]. The idea of a submersible bridge is that normally all water [illegible] roadway. If instead of arches there had been slabs over it, [illegible] r and we would have had a lesser area of

Mr. S. Srinivasa Raghava Charyar (Trichinopoly) : I would like to know more about the variation in flood level between wide extremes to which the author has referred in his paper. He also states that the rate of flow per cubic foot of opening varies very much. Will he also explain this more fully? What is the definite idea of a causeway and how does this idea differ from that of bridges? I would also like to know the basis on which the details of reinforcement are calculated.

Mr. B. Narasimha Shenoy (Calicut) : The idea is not that there is a choice between full height and a submersible bridge. The question is one decided purely by local conditions. Over a deep and well defined river cross section, it will not be safe to have a submersible bridge. Over a broad stream which is shallow, it is advisable to have a submersible bridge to keep down the cost of expensive approaches. The height of the bridge is also determined by the level of the approaches. A submersible bridge is therefore one purely dictated by local conditions and there are few cases where a real choice lies between the submersible and full-height bridges.

Mr. A. Lakshminarayana Rao (Masulipatam) : It is stated on page 3 of the Paper that a 24-feet span was decided upon as being the most economical span. In designing a submersible bridge we should see that the obstruction offered to water is the minimum possible. To have arches in the bridge is to have more area of obstruction to the water flow than we have in slab bridges. The design of a submersible bridge should provide for other stresses beyond road stresses. In one particular case I found that a twenty-feet span slab offered the least obstruction and was more economical than an arched bridge. Has the author considered this aspect of the question and, if so, what is his experience? I request the author to give his views whether submersible bridges have been found economical in all cases or only in some cases on account of local conditions.

Mr. W. A. Radice (Chairman) : Before asking Rai Bahadur Bhaduri to wind up the discussion I should like to enter into the discussion myself.

In some parts of India causeways at low level, without vents, are frequently damaged during the rains, causing recurring expenditure to be incurred for their repair which often aggregate to considerable sums.

We all know that for the protection of river banks a guide bund is preferable to a spur jutting out into the river, as the latter causes swirls and scour downstream. Similarly, as soon as the water flows over a causeway, the causeway acts as a vertical spur, causing scour downstream and the collapse of the causeway.

Our president, Mr. Stubbs, was kind enough to draw my attention to this feature of road construction and to suggest that as the repair of causeways in his province made constant annual inroads in his budget resources it might be advantageous to replace the ordinary type of causeway by a permanent structure, if such could be devised, safe against scour, at a cost somewhat less than the capitalised average annual maintenance and repair charge.

I had this question investigated and found that a concrete slab bridge supported on Franki piles could be constructed at about Rs. 120 per lineal foot of structure, if a number of such bridges were to be built, so as to distribute the cost of plant over a number of structures. These structures can be made in the shape of a submersible bridge, the slab roadway being kept just high enough to clear the ordinary depth of water during the rains, and high enough from the river bed to

prevent excessive scour from the water passing under the slab in high flood when the slab is submerged. As the slab is supported on pairs of Franki piles driven 20 to 25 feet in the river-bed, ordinary moderate scour cannot affect the stability of the structure and the very nature of the structure prevents dangerous swirls and exceptionally deep scour.

The Author has worked on similar lines and produced an excellent and cheap substitute for causeways in places where there is a rocky river-bed and is to be congratulated on his success in producing a cheap and satisfactory structure of wide application in rocky river-beds.

I have risen to make these remarks in order to let the delegates of this Congress know that the type of structure I have described above provides an equally cheap and satisfactory solution in friable river beds and I shall be glad to give full particulars of my design to anybody interested.

Mr. S. G. Stubbs (President) : In this connection I may mention that Mr. R. A. Fitzherbert (Bombay) told me that he had seen slabs of concrete laid directly on sand without any foundation. I wish he will tell the Congress something about it.

Mr. R. A. Fitzherbert (Bombay) : There are many comparatively small causeways in the Southern Circle of Bombay Presidency. The average span of most of them would be about 300 feet. We placed thick slabs of concrete on the downstream side of the causeway directly on the sand instead of having an apron wall. We did this as an experiment only but it proved quite successful and we have now used it in other places. I think the average velocity of the stream at most of these places is about 8 feet per second.

Mr. S. G. Stubbs (President) : If we could place concrete slabs directly on sand like this, it would be a very economical way of dealing with Nullah Crossings.

Rai Bahadur S. N. Bhaduri (Author) : About twenty-five years back in the Central Provinces very wide but shallow rivers with sandy beds were made passable for traffic by dumping rubble stones along a predetermined alignment. As some of these stones got buried in pits scoured down-stream of the line, more stones were added and after a few years a stable sub-grade was secured for a fair-weather and sometimes for a low Irish bridge.

Mr. S. G. Stubbs (President) : Does not the obstruction caused by the stones create a scouring action ?

Rai Bahadur S. N. Bhaduri (Author) : Trouble was experienced with scour in the beginning but persistent treatment by adding rubble stone year after year overcame it. In Gwalior rock is found from five to ten feet below the bed of most of the rivers and consequently not much difficulty is experienced with foundation.

We had to make the Chaoli bridge of cement concrete because we were working against time. The bridge is on the boundary of Gwalior State on the Indore-Ujjain-Patan-Ajmere road which provides access to Ajmere through a number of Indian States.

In Gwalior we wished to adopt an uniform width for these bridges so that steel centerings made could be utilized on different works. Steel centerings were first made for a bridge of 30 spans across the Chambal River near Suwasra on the B. B. and C. I. Railway. This bridge was completed on the 30th June, 1932, and on the 12th July there was a flood of twelve feet over it. The reinforced cement concrete arches of the bridge, which had

not sufficient time to set properly, stood the test of flood without any damage whatsoever.

In designing submersible bridges, it is, of course, necessary to allow as much waterway as possible. The question of lime concrete arches for bridges has been referred to by one of the members. In masonry works for irrigation channels in the Central Provinces lime concrete arches were used by me on a few works as an experimental measure. It was found that the alternate wetting and drying creates some deteriorating action in lime concrete with the result that concrete from the soffit of the arch falls to the ground in chunks.

Even in road bridges this trouble has been experienced. I would not, therefore, advise lime concrete to be used for arches of road bridges anywhere. For arches of submersible bridges lime concrete should never be used.

About the height of piers: The economic span is about twice the height of the pier. Steel centerings were made for cement concrete arches of 24 feet span as this span was found suitable for a large number of streams. It was not possible to make the height of piers of all the submersible bridges equal to one half of the span owing to local peculiarities, without unnecessarily increasing the cost.

Mr. Dildar Hussain (Hyderabad State): But why use arches?

Rai Bahadur S. N. Bhaduri (Author): I found that beam and slab construction for submersible bridges gives rise to considerable vibration in the stucture when water passes over it.

Arches are more easily built and the soffit presents a smooth surface to the water passing along it. Moreover, centerings made for cement concrete arches could, with slight modification, be used for stone arches also. In Gwalior good building stone is easily available and road bridges not subjected to submersion are cheaply made in stone masonry.

Some members asked for calculations to supplement the paper under discussion. For small arches this does not appear to be necessary. Moreover detailed calculations have already been given in last year's paper (Paper No. 38 in the Proceedings of the Third Indian Roads Congress, regarding Parbati Bridge) which may be consulted if necessary.

Mr. Narasimha Shenoy has replied to the other points raised by some of the members and there is no need to refer to them again. To adopt a beam and slab construction for a submersible bridge is to invite trouble in the shape of the tremendous vibration which is set up by flood waters passing under the decking. In the case of arch bridges, the water passes smoothly along the soffit. The question of vibration set up in beam and slab bridges by flood water is not a mere theoretical one; it is a practical difficulty as anyone who has stood on a slab bridge during a flood must know.

I have great pleasure in proposing a vote of thanks to Mr. Radice for the trouble he has taken in occupying the chair during this discussion.

CORRESPONDENCE

I.—Comments made by Mr. C. L. Katarmal, State Engineer, Orchha State, by post on Paper No. C.

I congratulate Rai Bahadur S. N. Bhaduri for his very excellent paper on reinforced cement concrete submersible bridges constructed in Gwalior State,

I am not in the least against the use of reinforced cement concrete in structures. But I would like to remark that it would have been more economical if piers in the case of Chaoli bridge too had been of coursed rubble stone masonry —even if good stone had to be carried from some other nearest place—instead of reinforced cement concrete which to me looks to be the main cause of such a high cost for a small bridge of this size. Rate according to detail on page (2C) of the paper comes to Rs. 381-12 per foot run of bridge.

I may be excused to give an instance of a similar type of bridge 1,150 feet in length which I constructed about four years back over Jamni River at Sewari about 10 miles from Orchha railway station, in this State, and where the cost was much too low. There already existed a zig-zag bridge of olden times over 1,000 feet in length at this site starting from one side of the river and ending at almost its (present) centre, and I had to join this new bridge with the old one where it ended, so that the total length was a little over 2,150 feet. The old bridge too looked a complete one (for olden times) for the whole width of the river. It looked that the river changed its course. The new bridge has 14 feet high, piers of coursed rubble stone masonry on 3 feet thick reinforced cement concrete bases moulded on hard rock foundations, and spans of arches up to 25 feet. The bridge has stood the test of floods very well. The rate per foot run of bridge is Rs. 80.

II.—Reply by author (Rai Bahadur S. N. Bhaduri) to the comments made by Mr. C. L. Kartarmal by post on Paper No. C.

I am thankful to Mr. C. L. Kartarmal for his note on submersible bridges constructed in Gwalior State.

As mentioned in the body of Paper No. C. referred to above, the piers in the case of the Chaoli bridge had to be made of cement concrete as good stone suitable for masonry work was not available within a reasonable distance of the work. Basalt stone boulders obtainable at a distance of about seven miles were very difficult to dress to shape. Moreover, we were working against time to complete the arches before the rains set in and therefore had to construct the piers in cement concrete. By doing so, each pier was cast in one day, and the great saving in time thus made, enabled us to complete the arches just before the rains.

The centerings were struck on the eighth day and side walls were constructed three days after the centerings were removed.

The haunches were filled with weak cement concrete (proportion 1 : 4 : 8). Two days after filling the haunches, or fifteen days after striking the centering, the Chaoli bridge was subjected to an unexpected flood of four feet above the road level. No damage of any sort was done to the bridge.

As mentioned in the paper, the piers of all other bridges were built of coursed rubble masonry.

Reinforced cement concrete arches for submersible bridges made in Gwalior State have given no trouble so far.

The approaches of the Chaoli bridge had to be made with an apron wall down-stream for a length of about 500 feet to prevent scour and this increased the total cost of the bridge.

Where good stone suitable for arch masonry is obtainable nearby, stone arches are likely to work out cheaper than reinforced cement concrete arches but for quickness of construction, neatness of appearance and strength, reinforced cement concrete arches, if properly made, are difficult to beat.

Paper B.

Nawab Ahsan Yar Jung Bahadur (Chairman): I call upon Mr. W. A. Radice to introduce his Paper on "Franki Pile Foundations for Road Bridges."

The following Paper was then taken as read :—

PAPER No. (B).

FRANKI PILE FOUNDATIONS FOR ROAD BRIDGES

By

WILLIAM ARCHIBALD RADICE, B.A.(CANTAB), A.M.INST.C.E., M.I.E.(INDIA).

For the past two years, the author has been entrusted with the exploitation of the Franki Piling system in India and has also inspected several important piling jobs on this system in Europe. This experience has convinced him that the Franki piling system is scientific and provides unequalled security. In this paper he proposes to put the fruits of his experience before the Road Engineers of India, as he feels that this piling system is effectively a useful new tool to the hand of the Structural Engineer and especially to the Bridge Builder.

WHAT IS A FRANKI PILE?

For a full description of the Franki pile system the reader is referred to the publications obtainable from the concessionaires exploiting the system in India.* For the purposes of this paper it will suffice to say that the Franki bearing pile is a concrete pile cast in situ of high bearing capacity, the safe working load varying from 80 to 120 tons per pile.

An open ended tube is sunk into the ground in an entirely novel way. It is dragged down into the ground by the friction developed between a plug of unset concrete within the lower extremity of the tube, which plug is highly compressed by the repeated blows of a cylindrical 4-ton monkey working loosely up and down within the tube. The tube itself is never struck.

When the tube has reached good ground, it is held firmly by two side ropes and unset concrete is squeezed through the lower extremity of the tube into the surrounding subsoil (just like icing sugar is squeezed by a pastry cook over cakes) by the pressure generated by the blows of the monkey. By these means an expanded base of compressed concrete is formed in the good soil, its size being only limited by the compressibility of the soil. More concrete is then added, the tube is pulled up a few inches and the concrete is again rammed so as to squeeze it against the surrounding subsoil exposed by the lifting of the tube. This process can be regulated at will by regulating the number and intensity of the blows of the monkey at each lift of the tube so that the whole pile can be made as wide as one desires within the limits of the compressibility of the soil. Normally, the expanded base is made about 3 to 4 feet in diameter and, if the standard 19-inch tube is used, the shaft is usually 22 to 25 inches in diameter, according to the soil. If there are hard strata at intermediate points, expanded intermediate bulbs can be formed in them to increase the bearing power of the pile.

* The Braithwaite Burn & Jessop Construction Company, Limited, of Calcutta.

Should the pile be long or be exposed to lateral forces it must be reinforced. To do this, steel "cages" are previously prepared by arranging from 6 to 12 vertical steel rods on a 17-inch circle and surrounding them with a spiral of 3/8-inch rod at 4 to 8 inch pitch, welded to the vertical bars at each point of intersection. This cage is lowered into the tube as soon as about one half of the expanded base is formed, its dimensions being such that the monkey can work freely within it. The base is then completed and the shaft formed as usual, the concrete being forced outwards through the meshes of the cage.

The result is a more or less spherical mass of concrete formed below ground, about 3 to 4 feet in diameter surmounted by a highly rugous shaft 22 to 25 inches in diameter, slightly tapering outwards towards the top. Both the concrete and the surrounding soil are highly compressed, first by the sinkage of the tube itself and later by the ramming which forced the concrete out of the lower mouth of the tube into the soil.

QUALITY OF THE CONCRETE.

The standard concrete used is mixed as dry as possible, to a consistency resembling that of brown sugar, and in the proportions of 1,560 pounds of cement, 90 cubic feet of stone chips and 45 cubic feet of sand.

As some engineers have entertained doubts as to the effect on unset concrete of the ramming it receives in the process of forming a Franki pile extensive tests have been carried out on concrete cut out of Franki piles both of recent formation and also from piles a number of years old. A typical testing house report is reproduced :—

"The concrete examined, taken from various Franki piles, is of great compactness. On cleavage, the aggregate breaks across the elements composing it.

The specific gravity is high, absorption of water extremely low and nearly totally watertight. Resistance to crushing is very high and in no case have any construction defects or planes of weakness appeared, the concrete is perfectly homogeneous.

The proportion of cement to aggregate is 1 to 6, carbonic acid is practically non-existent. Resistance to the action of acids is considerably higher than is the case with ordinary concrete of like proportions.

The following numerical results were obtained in the tests.

Specific gravity—average 2·45.
Water absorbtion—average 0·73 per cent.
Permeability of a cube 8 inches by 8 inches under a pressure of 735 pounds per square inch—nil.
Ultimate crushing strength—7,730 pounds per square inch."

BEARING POWER OF FRANKI PILES.

Calculations of the bearing power of piles lack precision owing to the number of factors to be taken into account and the uncertainty of their exact values. Even when calculations are made conscientiously they can only give approximate indications whose practical value depends to a great extent on the good judgment of the computer and his knowledge regarding the strata pierced and the characteristics of the piles used.

The building up of pile formulæ has interested engineers and scientists all over the world and a very large number has been evolved. Those now in general use can be divided into two classes:—

(a) Dynamic formulæ depending on the measure of the refusal to penetration of piles of a given weight under a specified number of blows from a monkey of known weight falling from a measured height.

(b) Static formulæ depending on the friction between soil and pile, and the bearing power of the soil under the base.

Dynamic formulæ cannot be applied to Franki piles for the following reasons:—

1. When the tube has been sunk to the required depth, the conditions of equilibrium of the surrounding sub-soil differ completely from those obtaining after the pile has been formed. The ramming of the concrete whilst forming the enlarged base and the shaft compresses the sub-soil considerably more than the driving of the plug and sinking of the tube.
2. The refusal measured is that of a smooth tube of comparatively small weight, the actual pile has an enlarged base, a highly rugous shaft and weighs considerably more than the tube.
3. When the tube is being dragged down by the plug, the dispersal of the kinetic energy of the monkey cannot be measured, this leads to the adoption of excessive factors of safety.

The dynamic formulæ most in use take the shape:

$$R=\frac{W_m^2 h}{Sr(W_m+W_p)} \qquad \text{.........................(1)}$$

Where R = the safe load in tons; W_m and W_p = the weight of the monkey and of the pile respectively in tons; h = the drop of the monkey in inches; r = the penetration of the pile in inches under one blow of the monkey and S = a factor of safety, usually 4 to 6.

Applying this formula to a Franki pile, W_p must be the weight of the tube, say 2·65 tons for a tube 33 feet long, and W_m = 4 tons.

If a safe bearing power R of 70 is required the penetration for a 4 feet drop of the monkey would have to be:

$$r=\frac{4\times 48}{6\times 70\,(4+2{\cdot}65)}=0{\cdot}275 \text{ inches per blow.}$$

To people accustomed to ordinary friction piles this refusal would seem much too large. Against this, innumerable test loadings of Franki piles are available for which refusal observations have been made. In one case the refusal was 0·039 inches per blow, in another 0·591 to 0·787 inches. In the former case, the Franki pile when made registered a greater settlement than in the latter. Obviously the application of dynamic formulæ to the Franki tube have no absolute value, but ultimate penetration measurements on the tube can be used advantageously to compare different piles in the same soil.

Comparative refusal measurements on the tube sunk near an exploration bore hole confirm the resistance of the various strata as ascertained by the boring and set up a standard by which it is easy to recognize when,

in other neighbouring pile locations, the tube has reached the good soil. Otherwise penetration measurements on the tube cannot produce an absolute factor for calculating the bearing capacity of Franki piles. Static formulæ are in effect the only formulæ which can be usefully employed.

Static formulæ are generally in the form

$$R = A_b\, p + A_s\, \mu \text{..........................(2)}$$

Where $R =$ the bearing power of the pile; A_b and A_s = the areas of the base and the surface of the shaft respectively; p = the resistance of the soil under the base: μ = the co-efficient of friction between concrete and the soil.

The most convenient formula of this type is:

$$R = \sum_{n=o}^{n=m} \left[D_n\; A h_n\; tan^2 \left(45° + \frac{\phi_n}{2} \right) \right]$$

$$+ \sum_{n=o}^{n=m} \left[D_n\; \mu_n\; p\; (tan^2 \phi_n + 1) \left(\sum_{o}^{n-1} h + \frac{h_n}{2} \right) h_n \right] \text{..................(3)}$$

Where n = the serial number of each distinctive layer of the soil beginning from ground level and counting downwards.

m = the highest value of n.

D_n = the weight in pounds of one cubic foot of the material forming layer n.

h_n = the thickness in feet of layer n.

ϕ_n = the angle of repose of the material in layer n.

μ = the co-efficient of friction between the material in layer n and concrete.

$\sum_{o}^{n-1} h$ = the depth in feet below ground level of the upper surface of layer n.

A = the cross sectional area in square feet of the base of the pile.

p = the perimeter in feet of the shaft of the pile.

R = the safe bearing power of the pile in pounds.

This formula takes the following factors into account:—

(1) The bearing power of the soil under the base of the pile.

(2) The increase in this bearing power due to the depth of the soil above it.

(3) The lateral friction of the soil against the shaft.

(4) The increase of this friction due to the depth of the layer in question.

(5) The greater cross section of the base.

(6) The increase in the co-efficient of friction of the soil against the shaft due to the double compression of the soil, first by the

sinking of the tube and later by the ramming of the concrete forming the shaft.

(7) The increased resistance of the soil in cases where piles are driven at the bottom of deep excavations.

The 6th factor above is covered by a judicious choice of the value of μ. Where the shaft is very rugous and the soil well compressed the value of μ can be taken as high as the internal co-efficient of friction of the soil itself, namely $\tan \phi$.

The above formula can also be expressed in the more general form :

$$R = D \tan^2\left(\frac{\pi}{4}+\frac{\phi}{2}\right)\left(\int_0^h x\,dM_y + \mu\int_0^h y\,dM_x\right) \qquad \text{(4)}$$

Where dM = the vertical projection and dM_y = the horizontal projection of an element dM of the external surface of the pile.

This formula can be applied to piles of irregular shape and especially to Franki piles with intermediate expanded nodes at interval up the shaft and of increasing diameter conewise towards the surface as the lateral resistance of the soil diminishes.

In Appendix I, values of the various functions of the angle of repose are given and in Appendix II a classification of soils and their characteristics. These values are approximate and should be used judiciously and only when reliable experimental data are unobtainable. In this paper numerical examples are given of the application of these formulæ to various Franki piles which have later been subjected to test loads and offer a direct comparison between theory and practice.

The above methods of computation apply to isolated piles. In bridge foundations piles are generally grouped together at more or less close spacings. In such cases other considerations come into play, since the frictional support from the soil surrounding the shaft suffers considerable modification.

It is especially in cases where piles must be closely grouped to carry large concentrations of loads over a minimum area that the Author has found Franki piles particularly advantageous. The enlarged base gives a positive, measurable bearing, irrespective of the lateral friction of the soil, which a pointed pile cannot possess. In effect the value of closely spaced groups of pointed piles, especially in plastic soils like clay, must always remain suspect and can only be ascertained positively by the expensive and difficult process of loading several contiguous piles simultaneously.

In the case of Franki piles the amount of concrete used in forming the base can be measured and from this a fair approximation of the area covered can be obtained. In several cases of groups where the piles were five feet centre to centre it was clear that the expanded bases of the piles were touching. Taking into account the high state of compression of the soil between the shafts and the obstruction offered to release of this pressure by the proximity to one another and the multiplicity of the shafts themselves, there can be little doubt that the whole mass of piles and the soil between their shafts acts on the strata below the touching expanded bases as a monolith. The bearing power of a group of Franki Piles must, therefore, be the bearing power of the soil underneath the expanded bases over the whole area covered by the group of piles.

The bearing power of a horizontal plane in any given soil increases with the depth and there are many formulæ which render it easy to estimate its value. The one which seems to suit the conditions best is:—

$$R = \frac{1}{6} D \frac{p}{A} h^2 \tan \phi \left(\frac{1 - \sin \phi}{1 + \sin \phi} + 6 \, \frac{1 + \sin \phi}{1 - \sin \phi} \right) \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where R = the ultimate bearing power in pounds per square foot of the soil at depth h.

D = the weight in pounds of one cubic foot of the soil in question.

p = the perimeter in feet of the whole group of piles.

A = the cross sectional area in square feet of the whole group of piles.

h = the depth in feet below ground level of the bases of the piles.

ϕ = the angle of repose of the soil in question.

In homogeneous soils the safe bearing value should be taken at one-fourth or one-sixth the value of R obtained as above. In cases where the bases are founded on a harder stratum than the upper strata, the value of R, if based on the characteristics of the softer upper layers, need not be divided by so large a factor of safety. Good judgment and experience on the part of the computer are necessary. In many such cases the Author has adopted one half of the value of R with excellent results as demonstrated by subsequent loading tests. In Appendix III values of the expression :

$$\tan \phi \left(\frac{1 - \sin \phi}{1 + \sin \phi} + 6 \, \frac{1 + \sin \phi}{1 - \sin \phi} \right)$$

are given for values of ϕ from 5 degrees to 50 degrees.

EXAMPLES OF THE APPLICATION OF THE ABOVE FORMULÆ.

1. In this case the length of the piles was 16 feet 9 inches and the composition of the sub-soil is given in the following table :—

Nature of strata		Thickness of strata in feet	Weight of cubic foot of the soil in pounds	Angle of repose
Earth	..	2·30	100	35°
Sand and Peat mixed	...	4·27	106	30°
Peat	...	1·64	62	15°
Wet sandy clay	...	4·11 4·42	118·5	25°

The average diameter of the base was 7·55 feet
„ „ „ „ shaft „ 4·36 „
The area covered by the base was 44·672 square feet
The perimeter of the shaft was 15·614 feet
„ „ „ base „ 23·721 feet

Applying formula (3) above we get.

$$R = \left\{ \begin{array}{l} 100 \text{ by } 2{\cdot}30 \text{ by } 3{\cdot}68 \\ 106 \text{ by } 4{\cdot}27 \text{ by } 3{\cdot}00 \\ 62 \text{ by } 1{\cdot}64 \text{ by } 1{\cdot}70 \\ 118{\cdot}5 \text{ by } 4{\cdot}11 \text{ by } 2{\cdot}47 \\ 118{\cdot}5 \text{ by } 4{\cdot}42 \text{ by } 2{\cdot}47 \end{array} \right\} \text{ by } 44{\cdot}672 + \left\{ \begin{array}{l} 100 \text{ by } {\cdot}7 \text{ by } 1{\cdot}49 \text{ by } 1{\cdot}15 \text{ by } 2{\cdot}30 \\ 106 \text{ by } {\cdot}577 \text{ by } 1{\cdot}334 \text{ by } 4{\cdot}43 \text{ by } 4{\cdot}27 \\ 62 \text{ by } {\cdot}268 \text{ by } 10{\cdot}72 \text{ by } 7{\cdot}30 \text{ by } 1{\cdot}64 \\ 118{\cdot}5 \text{ by } {\cdot}466 \text{ by } 1{\cdot}217 \text{ by } 10{\cdot}27 \text{ by } 4{\cdot}11 \end{array} \right\} 13{\cdot}614$$

$$+ 118{\cdot}5 \text{ by } {\cdot}466 \text{ by } 1{\cdot}217 \text{ by } 14{\cdot}53 \text{ by } 4{\cdot}42 \text{ by } 23{\cdot}721 = 87{\cdot}3 + 29{\cdot}8 + 46{\cdot}0 = 163{\cdot}1 \text{ tons.}$$

The calculated safe bearing power is therefore 163·1 tons.

In an actual loading test this pile behaved as follows :—

Test Load in tons		Deflection in inches
25	...	·04
60	...	·08
90	...	·12
125	...	·165
150	...	·20
175	...	·235
200	...	·28
225	...	·355
262	...	·500

It will be seen that up to 200 tons the deflections are proportional to the load, but with 200 tons and over the deflection increases more rapidly than the load. 200 tons can therefore be taken as the critical safe load. The safe working load should be somewhat below this, say 150 to 160 tons.

2. In another case the length of the piles was 24·77 feet. The nature of the sub-soil is given in the following table :—

Nature of the soil.		Thickness of strata in feet.	Weight of 1 cubic foot of the soil in pounds.	Angle of repose.
Yellow clay	...	4·92	103	40°
Sandy clay	...	8·20	94	40°
Wet sandy clay	...	4·92	118·6	25°
Grey quicksand	...	2·30	125	20°
Sandy clay	...	1·97	118·6	25°
Green clay	...	2·46	125	25°

The diameter of the shaft was 23.6 inches

" " " " base " 31·5 "

The area of the base was 5·325 square feet.

The perimeter of the shaft was 6·168 feet.

" " " " base " 8·235 feet.

Applying formula (3) above we get.

$$R = \left\{\begin{array}{l} 103 \text{ by } 4\cdot92 \text{ by } 4\cdot6 \\ 94 \text{ by } 8\cdot20 \text{ by } 4\cdot6 \\ 118\cdot6 \text{ by } 4\cdot92 \text{ by } 2\cdot47 \\ 125 \text{ by } 2\cdot30 \text{ by } 2\cdot12 \\ 118\cdot6 \text{ by } 1\cdot97 \text{ by } 2\cdot47 \\ 125 \text{ by } 2\cdot46 \text{ by } 2\cdot47 \end{array}\right\} \text{ by } 5\cdot325 + \left\{\begin{array}{l} 103 \text{ by } \cdot84 \text{ by } 1\cdot705 \text{ by } 4\cdot92 \text{ by } 2\cdot46 \\ 94 \text{ by } \cdot84 \text{ by } 1\cdot705 \text{ by } 8\cdot20 \text{ by } 9\cdot02 \\ 118\cdot6 \text{ by } \cdot466 \text{ by } 1\cdot217 \text{ by } 4\cdot92 \text{ by } 15\cdot58 \\ 125 \text{ by } \cdot368 \text{ by } 1\cdot132 \text{ by } 2\cdot30 \text{ by } 19\cdot19 \\ 118\cdot6 \text{ by } \cdot466 \text{ by } 1\cdot217 \text{ by } 1\cdot97 \text{ by } 21\cdot33 \end{array}\right\} \text{ by } 6\cdot168$$

$$+\ 125 \text{ by } \cdot466 \text{ by } 1\cdot217 \text{ by } 2\cdot46 \text{ by } 23\cdot54 \text{ by } 8\cdot235 = 22\cdot1 + 60\cdot1 + 17\cdot0 = 109\cdot2 \text{ tons.}$$

The calculated safe bearing power is therefore 109·2 tons.

In an actual loading test the pile behaved as follows :—

Load in tons.		Settlement in inches.
30	...	0·04
65	...	0·085
90	...	0·12
122	...	0·16
146	...	0·20
157	...	0·235

Up to 122 tons the deflections are proportional to the load but with 122 tons and over the deflection increased more rapidly than the load.

122 tons can therefore be taken as the critical safe load. The safe working load should be somewhat less, say, 100 to 110 tons.

SPEED OF EXECUTION.

The Franki pile driver is a very modern and powerful machine and can produce piles at a very rapid rate. This, combined with the high capacity of individual Franki piles produces an astonishing output of bearing power. In a case which recently came under the Author's notice several hundreds of Franki piles of 100 ton safe bearing capacity were being made through 57 to 66 feet of alluvium, silt and clay down to a confined bed of compact sand on which the expanded base was formed. Two pile drivers were at work and the average output over several months work was 72 piles per week. This is equivalent to 3,600 tons of bearing power per pile-driver-week.

Applying these results to a bridge foundation, suppose the bridge consists of 9 piers each weighing 1,000 tons and two abutments weighing 1,500 tons each resting on wells sunk to a depth of 70 feet in silt and clay. These wells would take at least six months to sink. If groups of Franki piles were used, some 120 piles would suffice and at the rate of 20 piles per week, one pile-driver could complete all the foundations in six weeks. The bridge structure on wells would thus require two working seasons, say, twenty months to construct if founded on wells and only one working season, say, eight months if founded on Franki piles.

LATERAL FORCES AND SCOUR.

Modern bridge specifications lay stress on the effects of lateral forces on bridges and their foundations and lay down rules for accurately defining them. These comprise the effects due to wind, traction and braking of the live load, pressure of the current against the piers, etc.

In dealing with foundations the computation of the effects of lateral forces depends entirely on the depth of scour of the river-bed during maxima floods. It is, therefore, highly important to form an accurate estimate of the maximum expected scour. It is with some degree of trepidation that the Author approaches this aspect of the problem since many eminent Bridge and Irrigation Engineers have devoted years of study to this subject and have evolved a series of formulæ for measuring river discharges and the scour to be expected in rivers in India. In his practice the Author has found these formulæ somewhat difficult of application frequently giving widely diverging results. He would, however, draw the attention of his professional brethren to a very valuable paper by Mr. G. Lacey to be found in the Proceedings of the Institution of Civil Engineers, London, in volume 229, page 279, entitled "Stable Channels in Alluvium."

In dealing with Franki pile bridge foundation designs, the Author has found it necessary to confine the use of simple pile and capping slab foundations to cases where the maximum scour does not expose more than about 15 feet of pile. Methods of dealing with deeper scours are suggested further on in this paper.

With moderate scours and lateral forces, groups of plain vertical piles do very well if carefully checked by computations. The large diameter of Franki piles (22 to 25 inches) and the considerable amount of reinforcement possible render them especially valuable in resisting bending moments.

Methods of doing so which have been extensively used by the Author and found most dependable may be found in Paper No. A (I) submitted to this session of the Indian Roads Congress by Mr. Guthlac Wilson and will, therefore, not be discussed here. When the lateral forces to be resisted are considerable it has frequently been found useful to utilize inclined Franki piles since they can be formed at inclinations of from 5 to 25 degrees to the vertical. In a recent design for a bridge consisting of 80 feet spans, each pier was founded on six inclined Franki piles arranged in two groups of three piles each. One pile in each group raked up or downstream, the other two diverged in the direction of the centre line of the bridge, all at an inclination outward of 1 in 5. Although, owing to their expanded bases, Franki piles can resist upward tensile forces of 30 to 50 tons each, in this case it was found possible to arrange matters so that under the worst combination of lateral forces no pile was stressed in tension. The interesting point in this case was that, the piles being 50 feet long, the base of the foundation covered an area 38 feet by 25 feet and yet offered a pier base only 5 feet thick to the current. It would be difficult to achieve so small an obstruction to the waterway combined with so wide and stable a base by any other method of construction.

The considerable power of groups of inclined Franki piles to resist lateral forces even in friable and erodible river beds makes it possible to design and construct cheap foundations quite capable of resisting satisfactorily the thrust from arch ribs. The difficulty of achieving this result in soft soils has tended to produce bridges with slab, beam and slab or bow string girder spans. Plain arch spans compare both æsthetically and economically with these types of construction and if there is a suitable stratum of good soil at reasonable depth (100 feet or less) the inclined Franki pile provides a cheap and simple means to reap these advantages.

In Paper No. A (II) submitted to this session of the Indian Roads Congress, also written by Mr. Guthlac Wilson, a very pleasing application of the Franki pile for road bridge foundations is described. In this case a bridge had to be cast across the neck of a series of lakes excavated by Calcutta Improvement Trust in order to fulfil the dual purpose of providing an ornamental sheet of water in a public park and provide filling material for the extension of residential areas on low-lying ground. Several rowing clubs use these lakes and it was necessary to provide an opening through which two rowing eights could pass, side by side, keeping the headroom as low as possible. Several types of span were investigated such as the low arch and the rigid frame but both were found to be about twice as costly as a cantilever span, shaped so as to simulate a low arch. Each cantilever balances on a knife edge beam resting on five Franki piles carrying 125 tons each. The anchor arms were shaped as boxes which contain the approach earth work and retain it acting as U-abutments. Their extremities rest on three Franki piles which act in tension when the cantilever arms are fully loaded and as bearing piles when the bridge is empty. The effect is pleasing, the bridge is cheap and has behaved excellently during the test loadings on completion. The sixteen Franki piles on which the whole structure rests were completed in as many days and were driven to a thick layer of confined sand at a depth of 72 feet.

In the case of rivers with friable river-beds where a reliable stratum at reasonable depth makes a piled foundation rational, but where the scour is expected to exceed 15 feet, the plain pile and slab type of foundation will not do and other types of foundation must be adopted.

The Author's favourite method is to drive the group of piles as usual but terminating the concrete shafts below ground at maximum scour level. This is quite easily done by forming the pile shafts as usual up to the desired level and then simply withdrawing the tube without further concreting. Whilst the buried Franki piles are setting, steel sheet piles are driven round them with an overlap in depth of 10 to 15 feet to form a coffer dam. If the subsoil at scour level is impermeable the interior of the temporary coffer dam is excavated by hand in the dry until the tops of the piles are exposed. A capping slab is then cast round them and the pier built on it, the sheet piles being pulled up as soon as the pier masonry rises above ground or water-level for use on the next pier. If the soil at scour level is not impermeable the material within the coffer-dam is dredged out until the tops of the piles are reached and then the soil between the pile heads is cleared by means of skin divers at reasonable depths, otherwise by water jet and air-lift pump. A concrete plug is then cast under water with a tremie amongst the pile tops and the excavation pumped dry.

Another method very efficiently developed by J. C. Gammon Ltd., of Bombay, is to cast one or more thin concrete rings about 10 to 12 feet in diameter and about 8 inches thick. These rings are sunk as wells by open dredging to a few feet below scour level. Piles are then driven through the bottom of these wells and brought up through the water, level with their tops. The wells are then plugged under water, dewatered, filled with sand and capped with a concrete slab on which the pier is built above water-level.

Of these two alternatives the Author prefers the first because the pier, if made of reinforced concrete, can be shaped like an inverted mushroom with a very slender stem, right down to scour level, offering a minimum of obstruction to the waterway and minimising eddies and local scour near the piers. The second method seems to obstruct the waterway when scour takes place, about as much as ordinary well foundations.

FORMING FRANKI PILES IN WATER.

When, as above, Franki piles are to be formed in water, the following process is adopted. Cylindrical sheaths of 16 gauge steel sheets are required, some one-fourth inch more in internal diameter than the external diameter of the Franki tube. These sheaths must be long enough to penetrate some 3 to 5 feet into the river bed and project about 12 inches above the surface of the water. One of these sheaths is lowered perpendicularly on to the bed of the river and enough dry gravel is poured into it to fill it some 12 to 18 inches in depth. The pile driver is brought directly over the sheath on a barge or on staging. The Franki tube is then lowered on a stout steel plate, concrete is tipped in the tube to a depth of 3 or 4 feet and rammed lightly to form a compact plug at the lower extremity of the tube. The steel plate is now drawn aside and the plugged tube is lowered inside the sheath until it rests on the gravel plug inside the sheath. When the concrete-plug in the tube is struck with the monkey, the gravel plug in the sheath consolidates and drags down the sheath with the tube, both penetrating into the river-bed. As soon as the sheath has penetrated sufficiently into the river-bed, ramming is stopped and the sheath is held by two light wire-ropes attached to [illegible] Ramming is then continued as on dry land and the tube [illegible] to the required depth sliding telescopically through the sheath. [illegible] tube is then held by the

side-ropes and the plug is chased out and the spread base formed as usual. As the tube is drawn up to form the shaft, its bottom orifice eventually comes level with the bottom of the sheath. In this position, the monkey is lifted out, the tube is filled with plastic concrete and pulled right out. This fills the sheath with concrete, the little water between sheath and tube being either driven out by the concrete flowing out of the tube as it rises or being absorbed in the concrete. The sheath thus acts as an underwater shuttering in which the concrete can set undisturbed into a cylindrical column of about 20 inches diameter. The sheaths are left in place to rust away. The result is an ordinary Franki pile up to about 3 feet below river bed, surmounted by a monolithic round column, the reinforcements being continuous from the enlarged base to the top of the column.

CONCLUSION.

It is, of course, impossible in a paper of this nature to convey more than a very superficial idea of the hundreds of useful applications to which this new element of construction lends itself. One thing, however, must have emerged from this discussion. It is insufficient to take the design of a bridge and then attempt to put Franki pile foundations under it. Most, if not all, of the advantages of the system will be lost. The only way to get the best of the system is to start with the question : is this a site suitable for Franki piles. It is not sufficient to find penetrable materials overlying good bearing strata at reasonable depths. Only an engineer who has had considerable experience in the design of bridges and of Franki pile foundations in a large variety of sites and conditions can answer this question efficiently. Should the answer be in the affirmative, then the whole conception of the layout, length of spans, type of foundation, type of pier, etc., etc., must be built up round the central idea of the Franki pile, its advantages and its limitations. Given these essential requirements, it is the Author's firm belief that the Franki pile will generally provide the best and often the only solution of difficult bridge foundation problems where piled foundations are rational. He hopes that, at the very least, he has enabled other engineers to get a first if superficial idea of the potentialities inherent in this novel structural expedient.

APPENDIX I.

ϕ	$\mu = \tan\phi$	$\tan^2\left(45^\circ + \frac{\phi}{2}\right)$	$1 + \tan^2\phi$
10°	0·176	1·42	1·031
15°	0·268	1·70	1·072
20°	0·364	2·12	1·132
25°	0·466	2·47	1·217
30°	0·577	3·00	1·334
35°	0·700	3·68	1·490
40°	0·840	4·60	1·705
45°	1·000	5·82	2·000
50°	1·192	7·56	2·430

APPENDIX II.

Nature of soil.	ϕ	D in pounds. per cubic foot.
Peat	0° to 15°	37·5 to 62·3
Mud	10° to 15°	106 to 112·5
Mould	35° to 40°	87·5 to 106
Dry sandy clay ...	40° to 45°	93.5
Wet sandy clay ...	20° to 25°	118.6
Dry hard clay ...	40° to 45°	103
Wet hard clay ...	20° to 25°	125
Dry sand	30° to 40°	100 to 106
Wet sand	40°	112·5
Quick sand	15° to 25°	118·5 to 125
Dry gravel	35° to 40°	112.5 to 115·5
Wet gravel	25°	118·5

APPENDIX III.

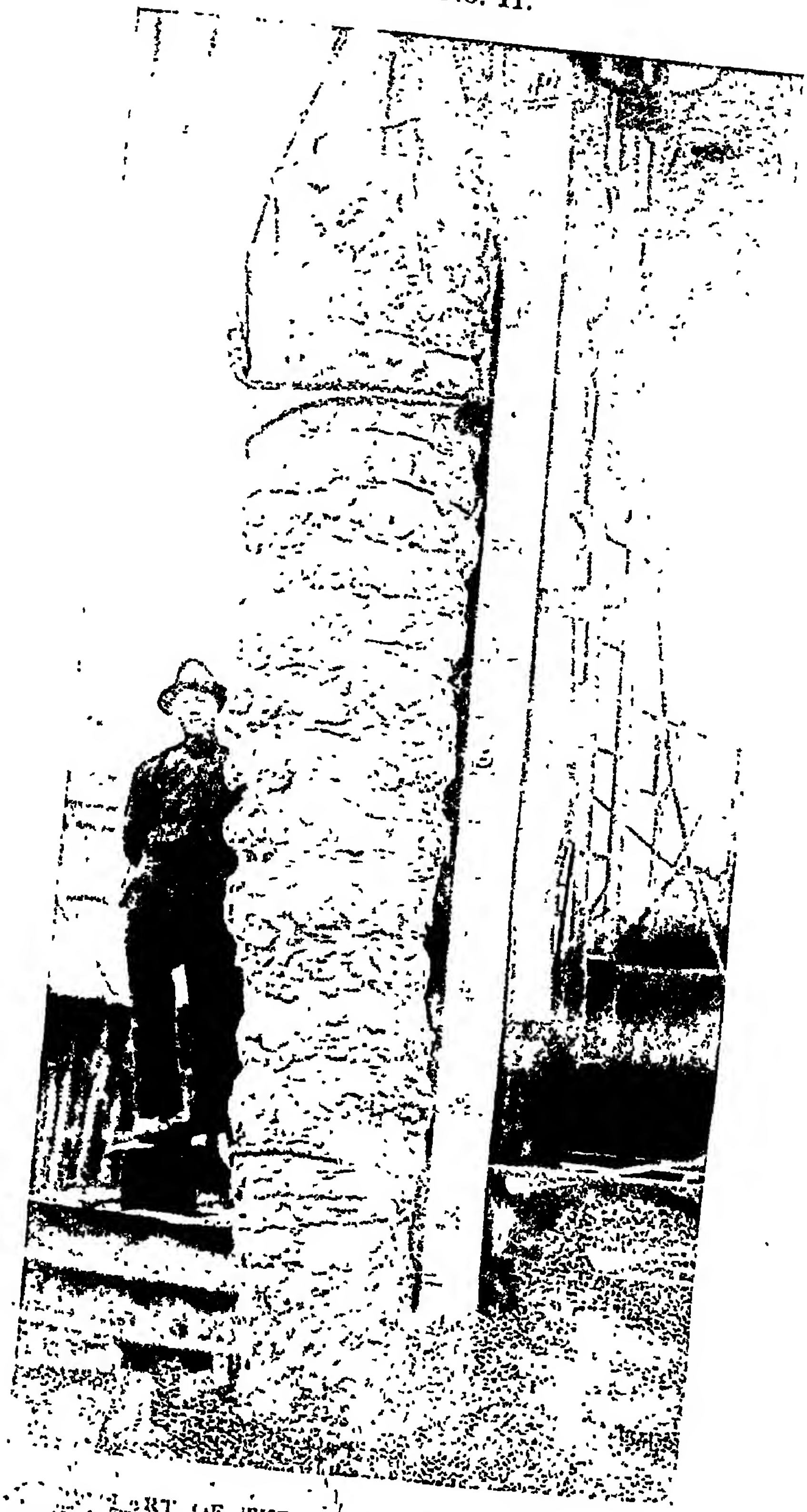
$$\text{Values of } f(\phi) = \tan\phi\left(\frac{1-\sin\phi}{1+\sin\phi} + 6\,\frac{1+\sin\phi}{1-\sin\phi}\right)$$

ϕ	$f(\phi)$
5°	0.698
10°	1.627
15°	2.890
20°	4.638
25°	7.090
30°	10.560
35°	15.325
40°	23.320
45°	35.152
50°	54.200

No. I.

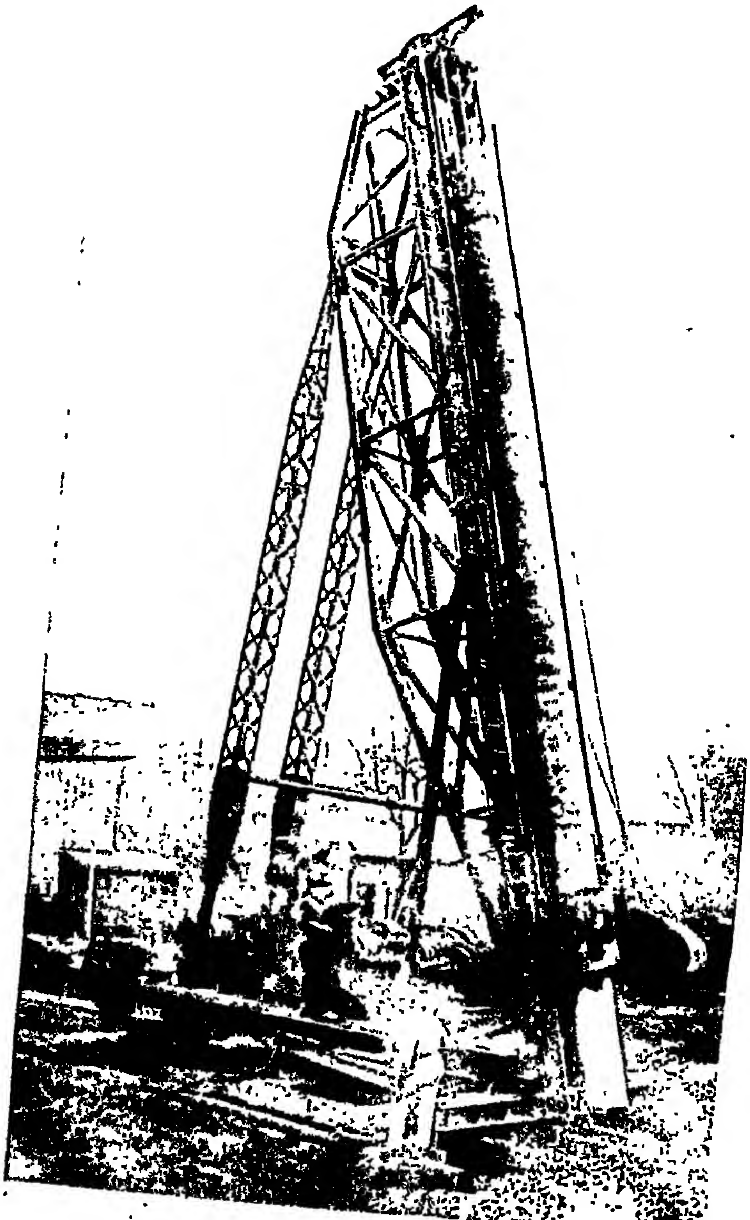
EXPANDED BASE OF A FRANKI PILE

No. II.



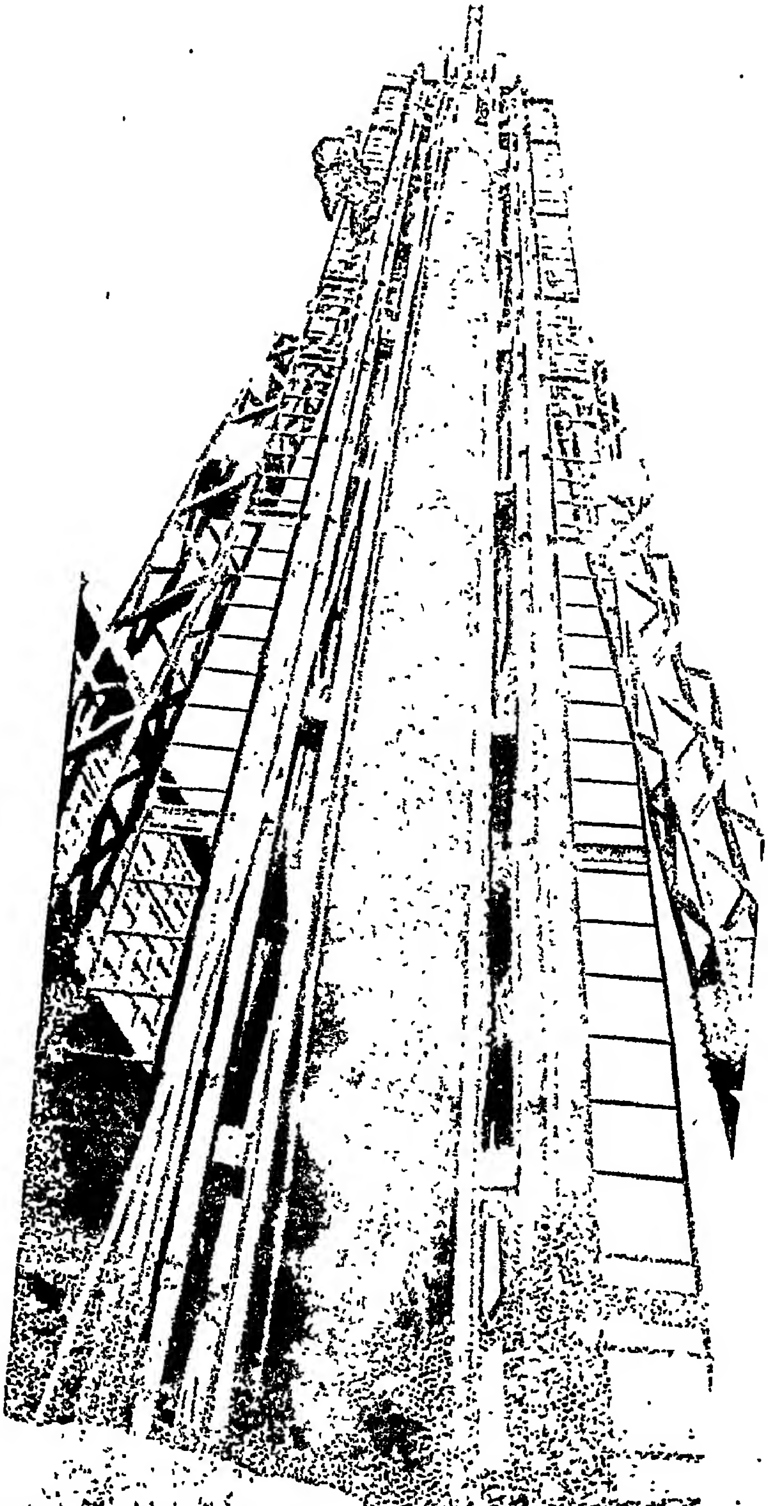
[illegible] PART OF THE [illegible] OF A [illegible] SHOW[illegible] AND INCREASING [illegible]

No. III.



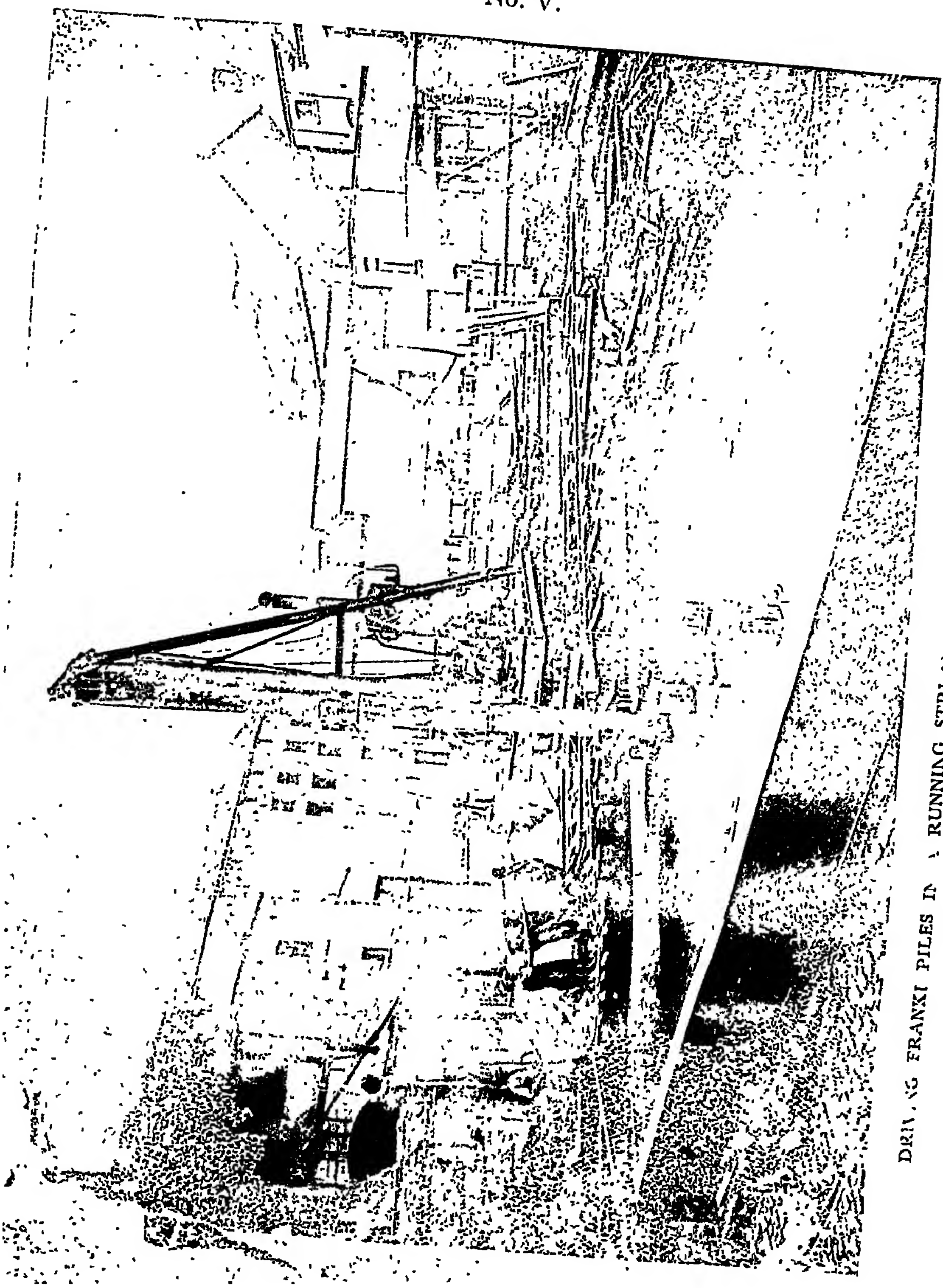
FRANKI PILE-DRIVER ADJUSTED TO [illegible]
INCLINED PILES

No. IV.



SHOW[illegible] ILE-DRIVER

No. V.



DRIVING FRANKI PILES IN A RUNNING STR[illegible] THIN STEEL SHEET SHEATHS

Discussions on Paper No. B.

Mr. W. A. Radice (Author): In introducing my paper on Franki pile bridge foundations I have nothing to say about the paper itself, but I think I should explain to the Congress that I am personally interested in the commercial exploitation of Franki Piles in India. I must apologise for presenting a paper in the circumstances and I trust my apology will be accepted in view of the technical interest this novel system of construction may arouse.

My doubts as to the correctness of the course I have decided to take were dispelled by the fact that my professional instinct as an engineer overcame my scruples as a commercial engineer and I am glad to see that your Committee appointed to scrutinise papers have apparently taken the same view by accepting this paper for reading.

Mr. D. S. Desai, B.E., of Messrs. Braithwaite & Co., Calcutta, has communicated to me by post, certain comments on my paper and these are as follows :—

"A very interesting paper describing an important phase of foundation engineering, which is not usually found in technical literature published in India is presented by Mr. W. A. Radice.

The author has clearly put forward his reasonings and arguments about Franki piles from his study of important piling jobs abroad.

After reading the paper, however, the writer has an impression that the fixing of size of the pile and its bearing capacity are still a matter of rough approximation. If the foundation stands safe without sinkage, as it should do, it is the evidence of good judgment of the designer and the contractor who carries out the work; but if by chance it sinks, tilts, settles or gives way, various causes of failure are put forward such as unknown conditions due to the variation of soil below and the like. When the real cause of failure is investigated, it is not usually given publicity just for the sake of the prestige of the builder. Recently in this country there were quite a few number of failures of bridges, but the engineering public was not aware whether the real causes of failures were properly looked into, investigated and published in technical papers. More literature along this line, i.e., pointing out causes in which current practice is faulty, will be very helpful. The writer shall be pleased if Mr. Radice from his vast experience in the design and the construction of bridges, can site examples of difficulties encountered or failures, if any, in the construction of foundation in Franki piles. It is the accumulation of such facts which gives an engineer a background of experience leading to safer construction because concrete examples are readily remembered and studied than the abstract rules and formulæ, because the young engineers, by reading of such examples can more quickly gather from the experience of others the knowledge of what to avoid and what limitations must be kept in mind, to insure safe and sound construction.

The author has given numerical example for carrying capacity of the Franki piles and also test loads with respective sinkage for direct compression, and comparison has been drawn between theoretical and experimental loads. It appears to the writer that one of the most important factors, namely time and duration of testing are neglected. If the tests mentioned in the paper are carried out with loads resting on the piles for 24 to 48 hours and if the settlement is measured and conclusions arrived at from these observations regarding the safe bearing capacity of piles, may [illegible] from the final values for the pile, as great changes often occur [illegible] subsided, or [illegible]

in the soils subsequent to the test loads. Also, it is not quite clear whether the pile under test will carry the same load under repeated application of load over a long period and what will be the settlement?

It seems to the writer that question regarding safe working load can be considered controversial, because few engineers will agree with the suggestion of Mr. Radice regarding the safe working load in the example, as the factor of safety will be less than two.

It seems that the author has not given any importance to the correct spacing of Franki piles. The writer will be pleased to know what the approximately correct spacing for Franki piles is; as the cast-in-situ concrete piles driven very closely are likely-to cause distortion, or crack, injuring the partly set concrete pile nearby. Also it is probable that unset concrete may be permanently injured by the vibration and additional earth pressure set up during the driving of the adjoining pile. There is also another possibility of cement being washed away if the pile is driven in water bearing strata.

If the underlying strata is not soft there will be a great difficulty in driving the piles through the intermediate strata; if by chance few feet of hard strata overlying the soft and unstable strata is met with, the shape of the pile is likely to be irregular and consequently the cross-sectional area of the pile may be reduced.

Another important point which is not fully explained is regarding the supporting power of friction piles in group. It is true that the supporting power of group of piles is not equal to the bearing power of an isolated pile multiplied by number of piles in a group. The writer will be obliged if the author would give a rational formula for this, as such formula usually is not given in ordinary text-books on bridge design.

The information regarding the cost of Franki pile (say, of 24 inch diameter) per foot run will be of great value. Besides this, it will be of great help in comparing the cost of Franki piles with many other systems of piles already used for foundations, such as screwcrete, screw piles, etc."

Mr. W. L. Murrel (Bihar): Mr. Radice's paper is a tonic for engineers who are keen on cutting costs and time. As regards time, how often are our sanctions, allotments and contracts delayed, so that the working season is well advanced before the contractor can yet make a start!

If we could, then, only reduce to weeks the months that are usually required for foundation work, what a boon the Franki pile would prove.

Though I have never seen any of these piles used on work, I am convinced of the general soundness and practicability of the procedure involved in their use.

There appear to be limitations, however, and I submit these for discussion.

The author gives alternative methods for carrying on the work between scour and surface levels, viz., upwards in open foundations from the top of the Franki piles or downwards through the bottom of wells.

The practical difficulty here seems to be to determine what is scour level. Take the case, for instance, of the road bridge which is to be constructed over the Amanat River in the Palamau District. Wash borings show a depth of 55 to 60 feet of sand overlying sandstone. Formulæ for theoretical scour depth would probably indicate a possible depth of scour of 25 to 30 feet.

The fact that scour actually goes much deeper is indicated by the behaviour of piers on the Railway bridge a furlong downstream. These

railway piers are on twin wells to about the same bed-rock level of 55 feet below the surface.

Two of the Railway piers have given trouble, the nature of which indicates definite scour right down to bed-rock level, about twice the estimated depth of scouring action. It is thus evident that scour level is not easy to determine.

The second point is the author's method of calculating the safe bearing power of the pile. This method depends on the tangents of the angle of repose of the material in the various layers penetrated.

At this stage, I would refer to the paper "The Laws of a Mass of Clay under Pressure" by M. A. Ravenor, M.Inst.C.E. in Vol. 240 of the Minutes of proceedings of the Institution of Civil Engineers, published after Mr. Radice submitted his paper. Mr. Ravenor points out that Rankine's formula for safe bearing power, which is based on the angle of repose of a homogeneous material, cannot apply to clay, as clay cannot be considered as being homogeneous (pages 621 and 622).

In the discussions that followed Mr. Ravenor's paper, a well-known engineer suggested that it was time to abandon calculations based on the friction-angle of clay!

On the other hand, Mr. Ravenor develops the theory that clay, under gradually increasing pressure, passes through three successive stages.

First it is elastic with deformation proportional to pressure. Under increased pressure—as the water is squeezed out, taking part of the colloids with it—the clay becomes indurated or hardened. With excess pressure, the clay becomes plastic and moves up round the seat of pressure.

The second stage is exceedingly important, as it results in the formation of a bulb of hardened material below the pile. It will easily be seen that if the pile itself has a bulb—as in the case of the Franki pile, the bulb of indurated material will be of very considerable dimensions, and the bearing power of the pile should be considerably increased. It would be interesting to know, therefore, how the two piles referred to by the author would have behaved under still further increased loading applied over a considerable period of time. I would like to suggest that the results would prove very satisfactory.

Finally, it might be pointed out that there is a very limited field in India where a concrete pile—and specialy Franki pile—should not be used.

In this great city of Hyderabad, with its tall and slender minarets and sky-scraping finials which have endured through many hundred of historic years, it seems out of place to mention earthquakes. But the engineer from North Bihar will tell you that all heavy foundation work must be avoided at all costs. He uses steel and iron screw piles as standard practice.

It appears that the great plains now being laid down by the northern tributaries to the Ganges, with their silt, sand, clay and water, form a fairly stiff and rigid mixture known as "gel". On agitation, however, as in the earthquake of 1934, the material becomes semi-fluid and is converted to a "sol", or is "puddled".

As a result of the 1934 "agitation" and especially towards the epicentral area where vertical accelerations reached the degree of 10 to 11 feet per second per second heavy buildings and bridge piers and abutments subsided, or "slumped".

Under these conditions, it is suggested that concrete piles would add to the weight of the building they were meant to support and, if the vertical accelerations did not cause them to break away from their superstructure, the piles would drag their superstructure down below normal ground level with them.

On the other hand, the steel and iron screw pile is simple to deal with. After the earthquake, all the piles were found, and the majority of them were unscrewed, straightened, and used again.

To just what extent this matter refers to our neighbours in Bengal and the United Provinces, is not for me to say. But if any of them would like to pursue the matter further, their attention is invited to the journal *Indian Engineering* for the 9th June, 1934.

Mr. G. Wilson (Calcutta): I am prompted to rise and discuss Mr. Radice's paper mainly on account of Mr. Murrell's comments in connection with the behaviour of piles in clay. Mr. Murrell refers to a recent paper by Mr. M. A. Ravenor in the Proceedings of the Institution of Civil Engineers on "The Laws of a Mass of Clay under Pressure." Mr. Ravenor's paper is based mainly on the results of a few carefully conducted experiments in British Guiana. But I feel it necessary to warn engineers from attaching too much importance to the conclusions expressed in the paper. The author produces an empirical formula which is dimensionally incorrect connecting the sixth root of the settlement with the unit bearing pressure on the foundation and gives as the proof of his formula the fact that this relation plots reasonably well as a straight line: it was pointed out in the discussion that it is a geometrical law, valid for any curve with a variable radius of curvature that the difference between the nth root curve and a straight line decreases with increasing values of z. Further, Mr. Ravenor's equation takes no account of time, an essential element in the settlement of clay strata.

The engineer who is interested in the settlement of structures built on clay should turn rather to the work of Professor Terzaghi. In works published over twelve years ago Professor Terzaghi demonstrated that the amount of settlement at various future times could be predicted with reasonable accuracy. The truth of Professor Terzaghi's theories, which are mathematically derived from elementary principles, has been proved by many observations on actual structures all over the world.

The action of piles on clay depends on the nature of the pile and on the nature of the clay. I am not referring to piles driven through clay on to a firm sand stratum, which is the ideal case, but to piles the whole length of which is within a clay stratum.

If the clay and the pile are such that the action of driving the pile does not transform the clay round the pile into plastic state, then the conclusion drawn by Mr. Murrell is correct. There will be a bulb below the end of the pile which will materially assist the skin friction on the pile in supporting the load.

If, however, the clay around the pile is made plastic, or "remoulded" during the driving of the pile, the state of affairs is quite different. The whole structure of the clay mass is disturbed, as may easily be visualized by considering the well-known fact that a sculptor or potter can soften clay, without addition of water, by moulding it in his hands. The consequence is that the whole stratum of clay within the piled area reconsolidates itself under the influence of its own weight with consequent settlement which drags the piles down with the stratum.

In such a case Franki piles driven by the method of boring which have already been used in England and elsewhere or screw piles are more likely to be suitable than percussion piles as they cause less disturbance.

Recently a large number of screw piles were put down by my firm in clay for a heavy building foundation and every pile was subjected to a test load 50 per cent greater than the working load. The results were remarkably uniform, except in the case of one pile, which had twice to be extracted from a considerable depth and redriven; in the case of this pile the settlement was 30 per cent greater than that of any other and two and a half times the average, which illustrates well the effect of remoulding the clay around this particular pile.

Nawab Ahsan Yar Jung Bahadur (Chairman): Mr. Radice has just given us a very interesting description about Franki piles. The great advantage seems to be, that as unset concrete is forced through, the base formed is of greater dimensions than the shaft and this gives a greater safe working load per pile. Doubts may be expressed with regard to the effect of continuous ramming on unset concrete. But, the author has assured us, as a result of extensive tests, that, if anything, the concrete produced is better.

There are, however, a few questions that I would like to ask Mr. Radice for enlightening us from his wide experience in this field.

1. Reinforced concrete piles as compared to steel are superior for the part above water. But some engineers believe that their use under water and below ground is prejudiced by being liable to deterioration. The life of steel piles is said to vary between 60 and 130 years according to the quality of steel and the sections used. I would like to know whether Mr. Radice had any opportunity of examining this aspect of Franki piles.

2. Usually 60 feet and a weight of 5 tons is the maximum for a normal reinforced concrete pre-cast pile on account of the difficulty of transport and pitching. With the introduction of unset concrete, these difficulties are greatly eliminated. What then is the maximum length to which Franki piles can be driven and probable stresses in the concrete at that height?

3. What is the comparative cost between Franki piles and steel bearing piles for conditions prevalent in India?

4. In determining the bearing power of piles Mr. Radice has set aside the dynamic formulae as determined by a series of test loadings. He therefore recommends the use of static formulae of the type given in equation 3 on page 4 (*b*) of the Paper.

The first part relates to the bearing power of the base.

(A) Is the value as determined for surface conditions going to remain the same, no matter at what depth the particular strata is met with?

(B) If, for instance, only sand is being met with, then the bearing power of soil will go on increasing. Is it not advisable to fix a higher limit for the bearing power of any particular strata?

The second part relates to the frictional resistance of the sides. The question arises as to what should be the value of μ, the coefficient of friction when a particular strata is met with at a certain depth.

These are some of the many indeterminate factors that induce many writers in this respect to adopt empirical formulae based on the dynamic

principle. I shall be obliged if Mr. Radice can point out some method of determining the above values.

The next question that arises is that of taper. From one of the photographs given in the paper, I see that the taper is formed towards the base. This is likely to give a greater bearing power to the piles. Mr. Radice has not taken this factor into account and I presume he has left it over as a further factor of safety. When many other factors have been included, it will be just as well to include the effect of taper if it is determinate.

In conclusion, I must thank the author for the valuable information given to the Road Congress on a subject which is increasingly getting popular due to the economy, convenience and speed with which a work can usually be completed. with the help of piles when foundation difficulties are experienced.

Mr. W. A. Radice (Author): I am extremely grateful to those delegates who have taken part in the discussion for bringing forward many interesting points, since this gives me an opportunity of supplying you with additional information on points of importance.

Mr. Desai. and other speakers also, have pointed out quite rightly. that the determination of the length and bearing power of a pile is not capable of exact determination. This is an uncertainty which is shared by all types of piles: failing actual loadings of test piles, the formulæ given in the paper permit of arriving at approximate results if an accurate knowledge of the various strata to be traversed is available through reliable borings but. as stated in the paper. a good deal depends on the skill and experience of the designer and the values he attaches to the various terms in the formulæ.

In this respect Franki piles have an overwhelming advantage over other types of piles if the borings reveal the presence. at reasonable depth. of good resisting strata such as rock, gravel, boulders. sand. confined quicksand. hard clay. etc. Since the enlarged base of a Franki pile, if formed on such a stratum. gives a definite bearing value. not dependent on uncertain factors like friction but on well established values. such as are used for open foundations. increased by the added bearing value due to the depth at which the good soil is found.

Personally. I would never carry out an important construction on a pile foundation unless proper loading tests have been carried out on test piles previously driven. unless the conditions of the preceding paragraph have been fulfilled. I may add that with Franki piles. the exploiters actually do, in their ordinary practice. guarantee that any Franki pile chosen at random and tested with a test load 50 per cent in excess of the working load recommended by them will not deflect more than a stated maximum. usually 1/4 to 5/16 of an inch, if they have been given opportunities of thoroughly ascertaining the nature of the subsoil.

Mr. Desai desires me to cite difficulties or failures of Franki pile foundations. I regret that I cannot do so for the simple reason that there have been none. Some years ago. a large building in Shanghai. based on Franki piles, sank considerably in the course of 4 or 5 years. It sank bodily and practically evenly. The reason for this is that the area in which the building was erected consists of soft mud to very great depths. Such material is totally unsuitable for any type of piled foundation. as the piles have nothing to grip or rest on, they merely add weight to the structure to be carried. The difficulty was, consequently, not due to the

piles but to the fact that piles were used at all. The proper foundation in such a soil is, of course, a caisson raft.

The next point I have noted is a reference to the time and duration of loading tests. This is a most important point. No reference to this factor was made in the paper as its purpose was to describe the applications and qualities of the Franki system and not to present a general treatise on the mechanics of soils, a very large subject. The reference gives me the opportunity of explaining that in all the tests of Franki piles I have carried out, in many cases imposing loads up to 300 and 350 tons on one pile, the load has been applied in steps of about 25 to 30 tons at a time. After each increment of load the pile has been carefully watched and no further increment of load has been added until the pile had come to a standstill and remained immobile for a period of at least 48 hours. After this period, a further increment was added and the process repeated.

From the figures of tests given in the paper Mr. Desai has come to the conclusion that the safety factor is less thant two. This conclusion is erroneous and the mistake is due to a confusion between the term "critical safe load" used in the paper and the ultimate failure load. I am glad of this opportunity to enlarge on this point.

I have inspected several hundreds of graphs giving the results of test loadings on Franki piles. In every instance, where the base is not on rock or similar unyielding stratum, the characteristics of these graphs are similar. As the test load is increased gradually, the vertical deflection first increases proportionately to the load increment, the load deflection graph being a straight line. At a given point, generally when the test load has reached 120 to 180 tons, the vertical deflection begins to increase more rapidly than the load increment, giving a curved graph, the curvature of which increases until failure occurs when the pile no longer comes to rest after each load increment but sinks steadily under the maximum constant load. In my experience this final failure has never been reached in a Franki pile tested in a soil suitable for piles, since the load required for failure of the pile by sinkage is considerably larger than the shaft of the pile can carry as a concrete column.

It will be clear that the "critical safe load" mentioned in the paper, i.e., the load where the vertical deflection begins to increase more rapidly than the load is very far from the point of failure, the latter being generally from 4 to 6 times as great. Speaking in terms of an elastic material like steel the "critical safe load" can be compared to the yield point and just as it is perfectly safe to stress steel nearly up to its yield point without overstressing or damaging it, so, in a Franki pile it is safe to use a maximum working load of 75 to 85 per cent of the "critical safe load." In the examples given the safety factor is not less than two, as assumed by my critic, but rather more like 6 to 8.

The next point raised is the correct minimum spacing of Franki piles in groups of piles. Fears have been expressed that with "cast in situ" piles close driving may injure piles already driven close by. This is a most relevant point.

Quite recently I have had to drive some 1,000 Franki piles all closely grouped, to carry heavy load concentrations; some of the groups covering areas like 40 by 60 feet.

I myself entertained doubts, before the work was commenced, and I referred the matter to the originators of the system in Belgium. I,

received their assurance that as the result of their worldwide experience of over twenty years there was nothing to fear if the piles were driven in succession of cross rows beginning from one end of the group. The reason for this is that the driving of the first cross row of a group compresses highly the soil round the piles, so that, when the second cross row is driven, the open side is much less resisting and any tendency for the soil to move is exerted in the direction away from the piles already driven. These instructions were followed carefully and after the piles had set several were denuded showing perfect results. The Franki pile being of considerable diameter (21 to 24 inches), the minimum spacing of piles in a group should not be appreciably less than 5 feet centres of piles. It should be noted that at this spacing the bearing value of the area below the capping slab has been developed up to over 4 tons per square foot, which can be increased to any required figure above the capping slab by designing such slab suitably. As this intensity of bearing is about four times as great as that possible with any other system of piling, it follows that the cost of capping slabs under heavy point loads over a group of piles is reduced to about 1/4 if Franki piles are used.

Reference has also been made to the possibility of the cement being washed away if piles are driven in water bearing strata. This is a danger to which all cast in situ piles are exposed but from which the Franki pile is entirely exempt, by the means adopted in forming the shaft of a Franki pile.

When the enlarged base of a Franki pile has been completed, the bottom of the tube is resting on a highly compacted mass of concrete, part of which is still in the tube, forming an impermeable compressed plug. More concrete is now dropped inside the tube and if the ground is waterlogged, this concrete is well rammed whilst the tube is raised some 4 or 5 inches only. It is clear that the 4 or 5 inches of concrete column previously inside the tube and now exposed by lifting the tube is under pressure due to the ramming and is at once squeezed outwards hard against the surrounding soil under great pressure. This pressure not only prevents water attacking the concrete but also compresses the surrounding soil squeezing out the water in it and closing any cracks or fissures through which water might percolate and wash out the cement. It is this very feature of the process which makes the Franki system so extremely reliable.

For the same reason, fear of distortion of the column of concrete in hard strata overlying softer strata can be dismissed entirely. The tube reaches the depth at which the enlarged base is to be formed by being dragged down by the blows of the monkey falling on the highly compressed plug of concrete which effectively closes its lower extremity. Thus all strata, hard or soft, are first penetrated by a rigid tube which is empty and can be inspected from above by means of a mirror before the pile is made.

As regards his request for a rational formula for calculating the resistance of Franki piles driven in groups, I would refer Mr. Desai to the last three paragraphs on page 5 (*b*) of the paper and to formula No. 5 on page 6 (*b*) where his requirements are fully dealt with.

Mr. Murrell refers to the difficulty of determining what is scour level. This is a difficulty which is not inherent to Franki pile bridge foundations and one that must be faced by the designers of any type of bridge foundations.

Under the heading "Lateral Forces and Scour" in my paper I have expressed some degree of trepidation regarding attempts to estimate scour depths and my difficulties in attempting to use existing formulæ.

In the case mentioned by Mr. Murrell of the Amanat River in the Palamau District, having 60 feet of sand overlying sandstone, there are indications from the behaviour of the piers of a railway bridge across the river, that scour can extend right down to bed rock level. Yet Mr. Murrell states that formulæ for theoretical scour depth indicate a scour of 25 to 30 feet. I do not know what formulæ Mr. Murrell has used, but if the results he gives are correct, all I can say that the formulæ used are either not reliable or have been misapplied. Most of the formulæ for scour known to me refer to channels in erodible materials of unlimited width and depth. In the case described I should say the question could only be solved by accurate data of maxima flood levels, discharges and size of channel and whether the banks are easily friable or not. Lacking these, the only safe assumption is that scour will extend to the maximum depth at which water borne materials such as sand, pebbles, etc., are to be found.

Piles must depend on the surrounding soil for stability and if, in the case mentioned, scour can extend down to the rock bed piles are obviously out of place there and well foundations, properly bedded some 5 to 10 feet in the rock by compressed air, is the proper type of construction to adopt.

Mr. Wilson has already dealt with Mr. Murrell's remarks regarding the bearing power of Franki piles in clay. I agree with Mr. Wilson in considering that Mr. Ravenor's results need confirmation. In clay I am convinced that any method used likely to squeeze the contained water out of the clay will expose foundations in that clay to gradual settlement over a period of years. For this reason I would not drive the Franki tube in clay, but sink it by perforation—a method that has been adopted successfully in several cases.

There remains, I think, only Mr. Murrell's last point regarding earthquakes for me to deal with. Mr. Murrell spoke of vertical accelerations of 10 to 11 feet per second per second. Such accelerations would not only totally destroy any structure built by human hands but would change the geography of the region, bring down hillsides, divert streams, etc., as I have seen in Assam.

Mr. Murrell's suggestion is that if iron screw piles were used, after the destruction of a bridge, these could be salvaged after the disaster and used again. It should be remembered, however, that iron screw piles cost about three times as much as Franki piles, for equal bearing power, so that the bridge in question would have to be destroyed some two or three times by earthquake before the iron screw pile could prove itself economically better than the Franki pile (*laughter!*).

Mr. M. S. Duraiswamy Ayyangar (Travancore): Are these Franki piles suitable for uniformly soft clay soils?

Mr. W. A. Radice (Calcutta): No!

Mr. Jagadish Prasad (Secretary): I propose a vote of thanks to Nawab Ahsan Yar Jung Bahadur (*acclamation!*).

Paper D.

Rai Bahadur S. N. Bhaduri (Chairman) :

I would call upon Mr. Dildar Hussain to introduce his Paper on "Reinforced Concrete Bridge across the Godavari River at Shahgadh in Hyderabad State."

The following paper was then taken as read :—

PAPER No. D.

REINFORCED CONCRETE BRIDGE ACROSS THE GODAVARI RIVER AT SHAHGADH IN HYDERABAD STATE.

BY

MR. DILDAR HUSAIN, B.E., M.I.E., (IND.), ASSISTANT CHIEF ENGINEER, P. W. D.
HYDERABAD (DECCAN).

Preliminary.—The Godavari River rises in the Western Ghats and after traversing a length of 900 miles, of which 700 miles lie in H. E. H. the Nizam's Dominions, it falls into the Bay of Bengal. In its course through the Dominions, the river has so far been bridged at six different places in order to provide communication between the different districts.

The following are the bridges so far constructed. Three more bridges across this river are under contemplation :—

	District.	Place where the bridge is constructed	Kind of bridge.	No. of spans.	Size of spans.	Object.
1.	Aurangabad.	Shahgadh	Reinforced Concrete Cantilever	17	60 feet	Hyderabad-Aurangabad road.
2.	Parbhani	Gangakhed	Plate Girder	15	60 feet	N. S Railway
3.	Nanded	Nanded	Masonry arched	20	60 feet	Hyderabad Nanded Road
4.	Nanded	Basar	Plate Girder	21	60 feet	N. S. Railway
5.	Nizamabad	Soan	Masonry arched	36	60 feet	Hyderabad-Nagpur Road
6.	Asifabad	Mancherial		44	80 feet	N. S. Railway

Situation of the Bridge.—The bridge at Shahgadh which has opened out communication between the districts of Bir and Aurangabad, forms an important link in the trunk communication between Hyderabad and Aurangabad and is situated about 286 miles away from the capital.

At the site of the bridge the river has well defined banks and runs through a deep and straight channel with a somewhat rocky bed. The drainage area is about 9,370 square miles, and the bed fall is about one in 2900.

Flood Discharge.—The highest flood level, as ascertained from local enquiry, was found to be at R. L. + 1391. From the cross sections of the river, the discharge, taking the average velocity as 10·80 feet per second, was found to be 300.000 cusecs. From Dicken's formula, $D = CM^{\frac{3}{4}}$, where the value of C varies from 150 to 1,000, the discharge, taking the value of C=372 for such a large catchment, worked out to 3,54,144 cusecs. The Chief Engineer's* formula,

$$D = CM^{\cdot 89 - \frac{1}{15}\log M}$$

where D = Discharge
C = Constant, 1550 in this case.
M = Catchment area.

gave a discharge of 470,580 cusecs.

* Nawab Ali Nawaz Jung Bahadur, F.C.H. Chief Engineer, now Consulting Engineer to the Government of Hyderabad.

Adopting this discharge, the highest flood level worked out to R. L. + 1397·60. This level has been kept at about half the rise of the arch, the springing level being R. L. + 1393·75. While the bridge was under construction, the river was in flood and it was observed that the flood level was R. L. + 1392 00, i.e., one foot higher than the level obtained from local enquiry. The uncertainty of local information, therefore, justified the caution in fixing the springing level at + 1393·75.

Description of the Bridge.—Although the region in which the bridge is built is one of trap formation, yet good building material could not be had in sufficient quantity in the close neighbourhood. Stone for archwork is not available anywhere within a radius of eleven miles. Hence considering the cost involved in paying expensive lead for stone, and the long time that would be required for completing the work, it was decided to have a reinforced concrete bridge. Competitive designs were therefore invited and that of Messrs. The Hindustan Construction Co. Ltd., was approved. This firm was also responsible for the construction.

The bridge consists of seventeen spans of sixty feet each. The decking comprises of a reinforced concrete slab 7½ inches thick and 18 feet wide between the wheel guards, carried in transverse direction over reinforced beams, which rest on reinforced cement concrete longitudinal girders and overhang by two feet two inches to give the necessary road width. The main longitudinal girders are designed as continuous beams supported on two reinforced cement concrete trestles, with overhanging cantilevers on either side, each making half the span. The trestles are composed of two reinforced cement concrete circular columns 4 feet and 4 feet 8 inches in diameter, according to the height, and are inclined at a slope of one in twelve in order to increase the stability against the lateral wind pressure ; and are joined together with three reinforced cement concrete braces spaced 12 feet 9 inches apart. The distance between the columns at springing level is 13 feet 9 inches centre to centre. The reinforced cement concrete footings of these columns are 7 feet and 8 feet octagonals for different heights of the trestles.

Thus it will be seen that each unit consists of a central span and two end cantilevers each making half the span, resting on two pairs of trestles. Between each unit a space of one inch has been left to serve as an expansion joint. The advantage claimed in this design is that in case any unforseen damage occurs to any one of the units, the same need not be transmitted to the adjacent units, which are separate from one another.

The parapet wall is of reinforced concrete and is 4 inches thick and 3 feet 9 inches in height above the road level, and is protected with a reinforced concrete kerb.

The roadway is finished with a wearing surface consisting of three inches of cement concrete in the proportion of 1 : 2 : 4 and with expansion joints 32 feet apart.

The bridge has no longitudinal camber. Cross drains, each 4 inches by 3 inches in section, 21 feet apart have been provided on either side of the road slab to drain the road surface.

The bridge spans the river at right angles to its axis of flow. The high approach banks are protected by means of reinforced cement concrete guard stones, each 6 inches by 6 inches by 4 feet, fixed in concrete bed at 4 feet centres.

Loading.—As per conditions specified for the design, the bridge is designed to carry a live load of 15-ton steam road roller which in working trim is taken as 16·25 tons. In addition to this a super load of 100 pounds per square foot is taken into account. No specific provision has been made for impact as a liberal margin has been provided by adopting low-working stresses, namely 600 pounds per square inch for concrete in compression, and 16,000 pounds per square inch for steel in tension, against 750 pounds for concrete in compression and 18,000 pounds per square inch for steel in tension as per recent practice.

Foundations.—Borings taken at the site of the crossing with G. O. Calyx Drill, showed that hard rock existed at depths varying from 6 feet to 25 feet.

Coffer dam islands were constructed and excavation of the foundation was carried out with the help of ordinary plank shoring. The planks were driven into the soil by means of heavy hammers. The pits being fully excavated a wall of gunny bags filled with earth was built parallel to the shoring, leaving a drain 1 foot wide in between, to carry the percolation water into a sump at one end of the pit, whence it was pumped out. This gave a fairly dry foundation trench which enabled concreting to be carried out without difficulty.

Due to the sandy nature of the river-bed, percolation was fairly heavy. As many as nine centrifugal pumps, detailed in the statement below, had to be employed to work continuously, three pumps working per shift of eight hours.

	Make.	*B. H. P.*	*Size of delivery.*
1.	G. C. Ogle's & Sons Ltd.	9/10	6 inches
2.	,,	9/10	6 ,,
3.	Shanks & Sons Ltd.	8/9	4 ,,
4.	,,	8/9	4 ,,
5.	,,	10/11	6 ,,
6.	,,	10/11	6 ,,
7.	Crossly Brothers.	11/12	6 ,,
8.	,,	11/12	6 ,,
9.	,,	11/12	6 ,,

To seat the trestles on safe foundation, the reinforced cement concrete footings have been taken down to hard rock, which is chiselled to a depth of 6 inches. In order to further strengthen the foundations of trestles and to guard against any percolation of water through unnoticed fissures, the two reinforced cement concrete column footings of each trestle are encased with a stone masonry wall of 3 feet thick and 5 feet high, and the open space between them and the strengthening ring is either filled with mass concrete or stone masonry.

Materials of Construction Aggregate.—The shingle from the river-bed has been used as the aggregate. It weighed 90½ pounds per cubic foot and contained 52 per cent. voids. Its grading was as follows :—

Retained on 1 inch sieve	1·86 per cent
,, ¾ inch sieve	60·9 ,,
,, ⅜ inch sieve	100·0 ,,

Sand.—The river sand was found to contain a certain amount of organic matter. It was thoroughly washed before being used. It weighed

112½ pounds per cubic foot and contained 36 per cent. voids. Its grading was as follows :—

Retained on 4-mesh sieve.		2·65 per cent.
,,	8 ,,	10·93 ,,
,,	16 ,,	31·80 ,,
,,	30 ,,	63·90 ,,
,,	50 ,,	95·70 ,,
,,	100 ,,	99·30 ,,

Cement.—The Char Minar brand Shahabad Cement was used in the construction. The supply used to be obtained by rail as far as Jalna, a station on the Hyderabad-Manmad line of the State Railway, whence it was conveyed by means of bullock-carts and lorries to the site of work.

Steel.—Tata's tested mild steel bars were used in the work.

Water-Cement Ratio.—The strength of concrete greatly depends upon its water-cement ratio. Any extra percentage of water besides just the quantity required to produce the necessary fluidity in the concrete to permit it to flow through and under the reinforcement bars, evidently makes it weaker. Similarly too little water is equally or even more harmful than too much of water, in as much as it will not be sufficient to hydrate the cement and the concrete so produced is bound to be porous and weak.

Experience has shown that the weight of water required to give a good working mix, when the sand and ballast are dry and non-absorbent materials, is to take 28 per cent by weight of the cement and add 4 percent by weight of the sand and ballast.

Keeping this criterion in view and using the above-mentioned materials in conrete with a proportion of 1 : 2 : 4, it was found that nearly 5·5 gallons of water were required per bag of cement. As sand and ballast were washed and used in wet condition, actually 5 gallons of water per bag of cement were found to be quite adequate.

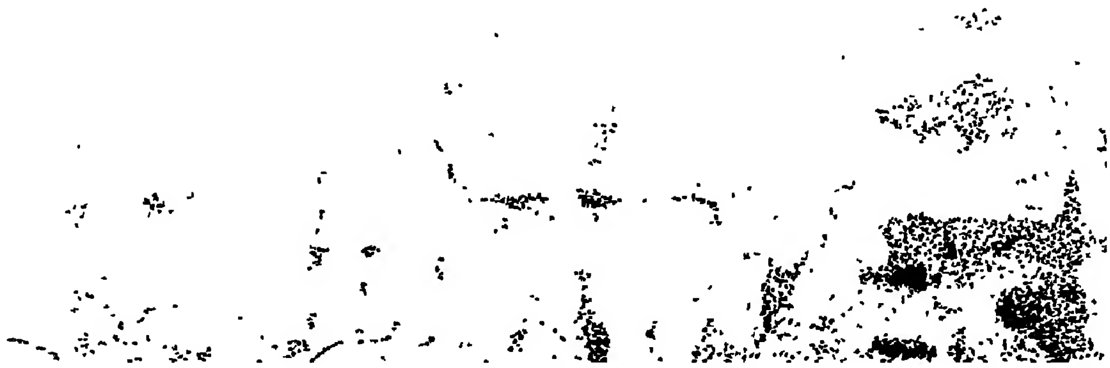
Centrings.—The steel centrings for the deck work in particular, presents an unusual feature in design. It consisted of four N-girders built up of channel iron, each 190 feet long spanning over three vents of the bridge. The N-girders were placed, one on either sides of each of the longitudinal main girders which were cast in situ, and the plates were bolted to them to form a box-like structure. After placing the reinforcement bars in position, the main and cross girders were laid all in one day, the quantity of handled concrete being 2,700 cubic feet. After a period of four weeks the plates were struck off, the N-girders were lifted and placed over ball-bearing rollers, and pulled forward to the next position. This arrangement facilitaed the work to be pushed through even during the monsoon when the river was in flood.

Period of Work.—The work was commenced on 26th November, 1931, and completed on 6th January, 1934, that is to say within a period of about two years and two months. The total cost of the bridge including the approaches was Rs. 7,61,230 in the State currency. This is equivalent to Rs. 6,52,285 approximately in British Indian currency. This gives a rate of Rs. 567 per running foot of roadway, about Rs. 31 per square foot of roadway, and Rs. 15 per square foot of opening and Rs. 10 per square foot of the elevation area, i.e., from road level to the average foundation level.

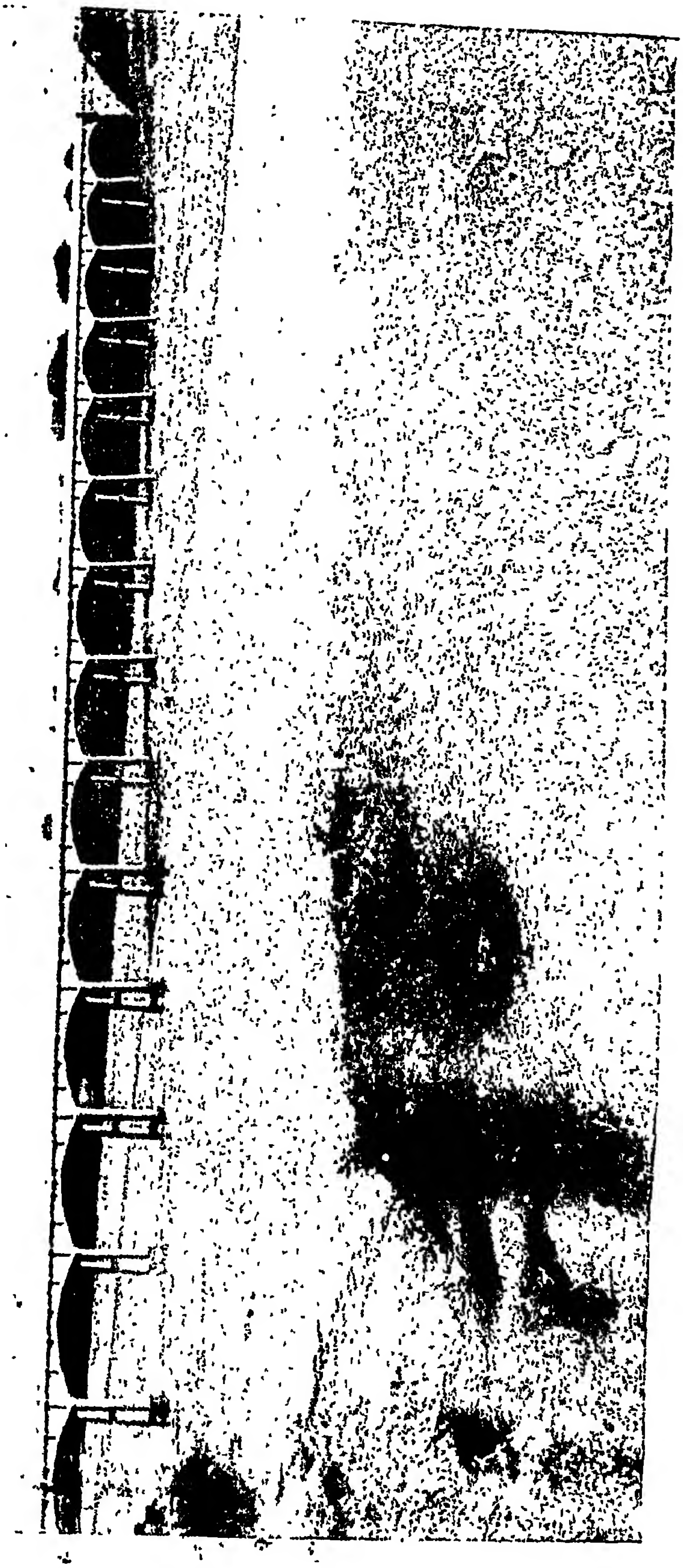
Conclusion.—The bridge was designed and constructed by the Hindustan Construction Co. Ltd., Bombay. Messrs. B. P. Kapadia, B.E.A.M.I.E., and K. C. Wadia, A.M.I.C.E., were the firms' engineers. On behalf of the Public Works Department of the State, under whose direction and control the design was examined, approved and carried out, the names of the following officers deserve mention :—

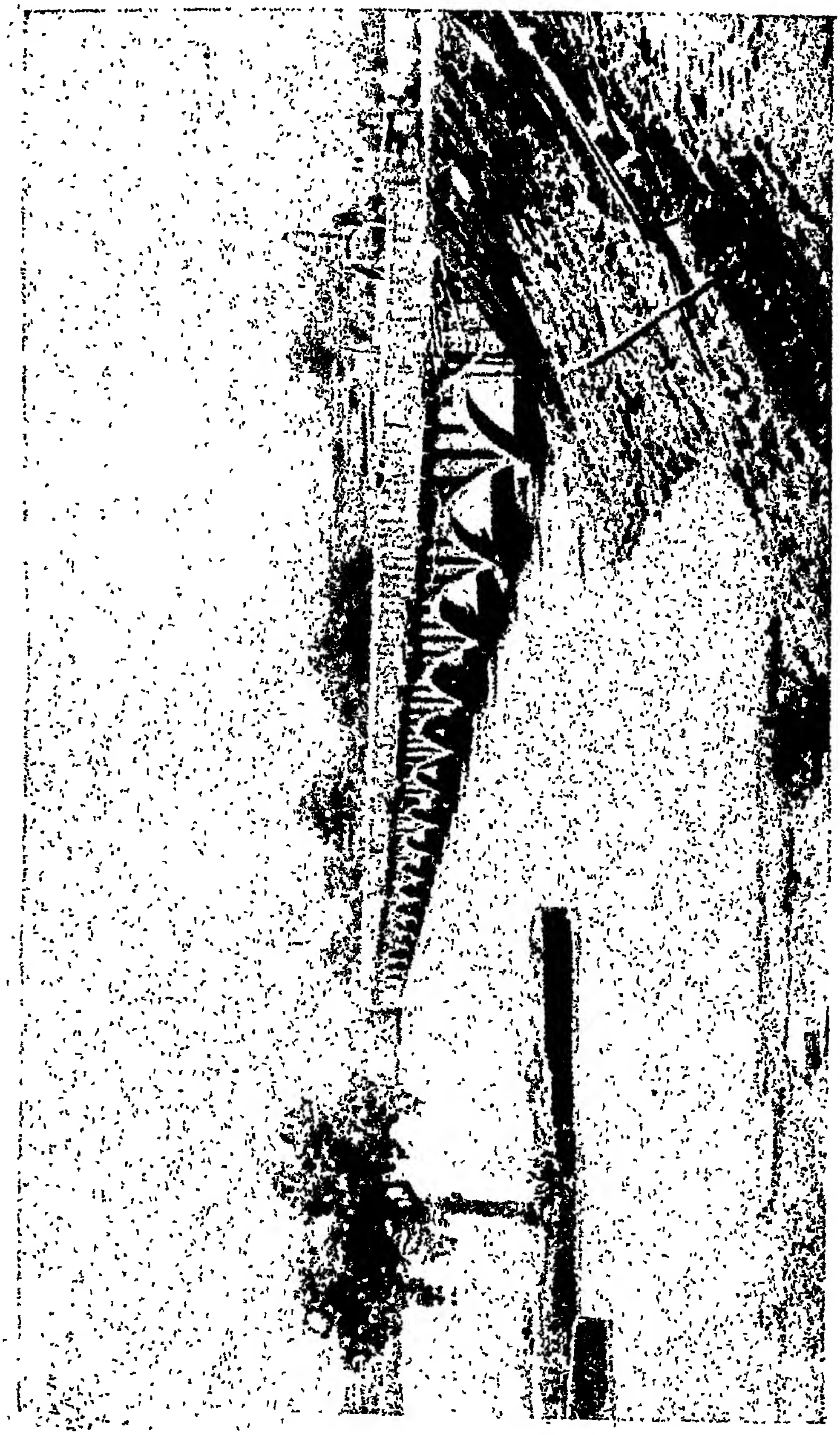
1. Nawab Ali Nawaz Jung Bahadur, F.C.H., Chief Engineer and Secretary to Government, P. W. D.
2. Mr. Hasan Latif, C.E. (London), Superintending Engineer, Aurangabad Circle.
3. Mr. Azmatulla, M.A., B.Sc. (Edin.), Executive Engineer, P. W. D., Aurangabad.
4. Mr. D. V. Rao, B.Sc. (London) A.M.I.E., Assistant Engineer in direct charge.

Although the writer had visited this work during the course of its construction, yet the present article is based on the information that was available in the records of the Executive Engineer's office, Aurangabad, and the Assistant Engineer's office at Jalna. In drawing up this paper I have to acknowledge the information placed at my disposal by Mr. D. V. Rao, B.Sc. (London), A.M.I.E., Special Officer, Well-Sinking Department, Hyderabad State, then Assistant Engineer in charge of the work, and Mr. Safdar Ali Shariff, B.E. (Osmania), Supervisor, P. W. D.

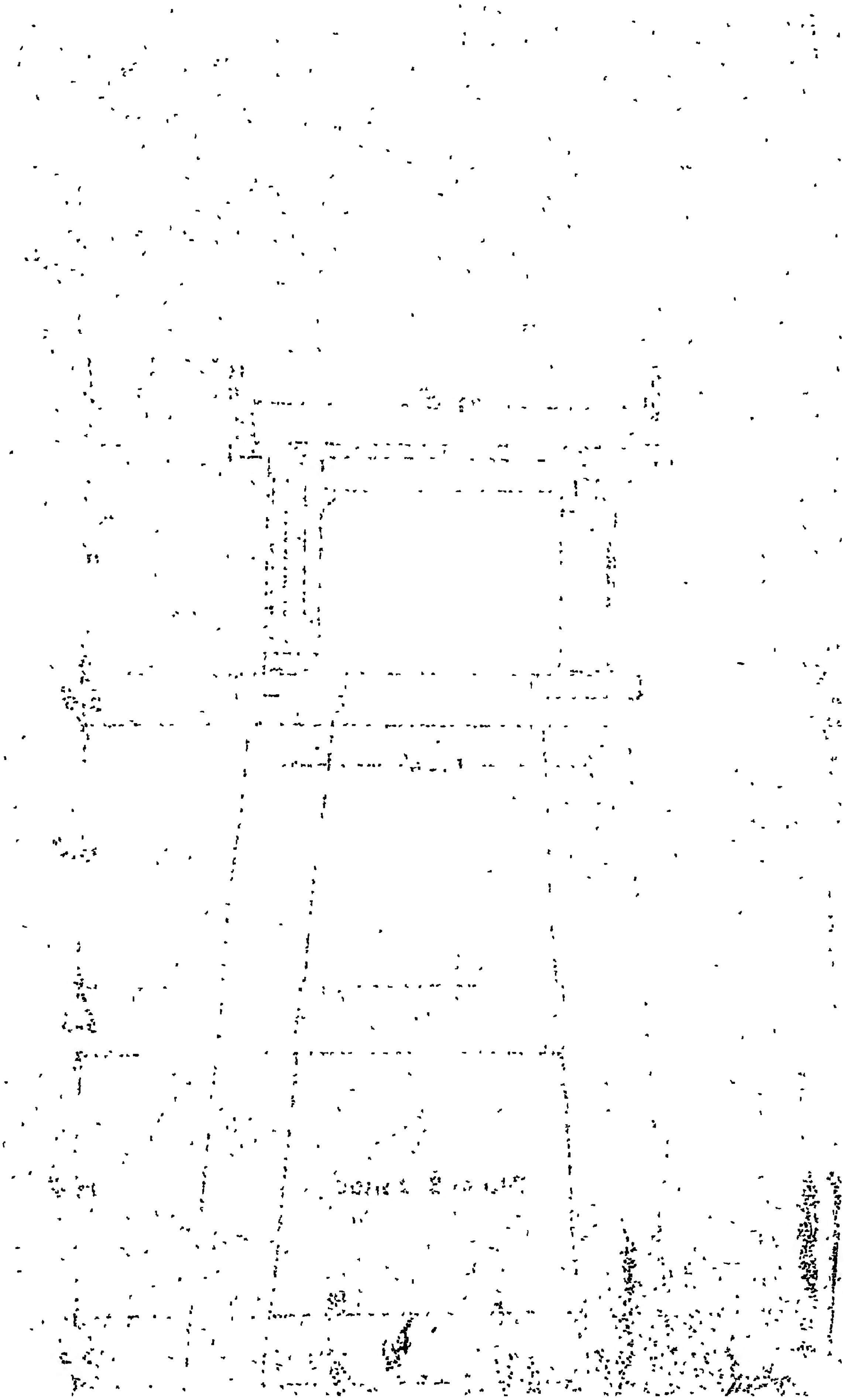


6(*d*)





Shahgadh Bridge nearly complete ; River in flood.



APPENDIX.

REINFORCED CEMENT CONCRETE BRIDGE ACROSS THE GODAVERI AT SHAHAGAD.

(H. E. H. THE NIZAM'S DOMINIONS).

DESIGN OF THE SUPERSTRUCTURE.

A. *The Square Slab.*

1. Effective dimensions of slab 12 feet by 12 feet
2. Taking a central live load of 9·75 tons, equivalent dead load is—
   $9{\cdot}75 \times 2 \times 2{,}240$ pounds $= 43{,}680$ pounds

Load per square foot $= \dfrac{43680}{144}$ $= 303$ pounds

Weight of $7\frac{1}{2}$-inch concrete at 150 pounds per foot $= 94$ pounds
Weight of Asphalt $= 22$ pounds

Total load per square foot 419 pounds

Load carried in each direction $= \dfrac{419}{2} = 210$ pounds per square foot

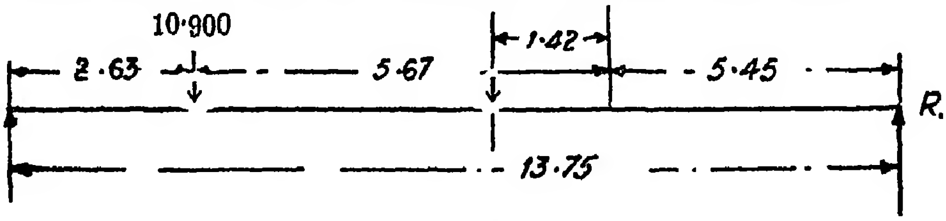
3. The slab is continuous
   Therefore maximum bending moment $= 210 \times 12^2 = 30{,}240$ inch-pounds
   Taking an average effective depth of $6\frac{1}{2}$ inches
   Moment of resistance $= 6{\cdot}5^2 \times 1140$ $= 18{,}200$ inch-pounds
4. Percentage of reinforcement $= \dfrac{30{\cdot}2}{48{\cdot}2} \times 0{\cdot}675$
   $= 0{\cdot}423$
   Area of steel per foot width $= 0{\cdot}423 \times 12 \times 6{\cdot}5$ square inches
   $= 0{\cdot}33$ square inch

Use $\frac{1}{2}$-inch diameter rods at 7-inch centres giving 0·34 square inch

B *Cross Girders.*

1. Effective Span = 13 feet 9 inches.
2. Dead load from slab and asphalt $= \dfrac{13{\cdot}75 \times 12{\cdot}5}{2} \times 116$ pounds
   $= 10{,}000$ pounds.
   Dead load of Cross Girder $= \dfrac{18 \times 12 \times 11{\cdot}75}{144} \times 150$ pounds
   $= 2{,}600$ pounds
   Total load $= 12{,}600$ pounds
3. Moment due to dead load $= \frac{1}{8}$ by 12,600 by 13·75 by 12 inch-pounds
   $= 2{,}60{,}000$ inch-pounds.

4. For maximum moment in the beam due to the super load of a 15-ton roller in working trim, the position of loads will be as follows :—



$$R = \frac{10{,}900 \times 2{\cdot}63 \text{ plus } 10{,}900 \times 8{\cdot}30}{13{\cdot}75} = 8{,}665 \text{ pounds.}$$

M = 8,665 by 5·45 by 12 inch-pounds = 5,67,000 inch-pounds.

Total M due to dead and live load
= 2,60,000 plus 567,000 = 8,27,000 inch-pounds.

5. With an arm equal to 21 inches

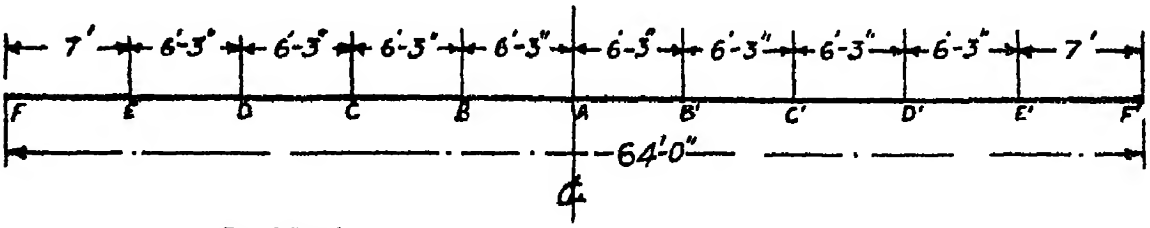
$$\text{Area of steel required} = \frac{827{,}000}{21 \times 16{,}000}$$

= 2·46 square inches.

Use four 1-inch diameter rods, giving an area of 3·14 square inches.

C. Main Girders.

1. For purposes of design, the span from centre to centre of trestles, viz. 64 feet, has been divided into ten panels, two end-panels of 7 feet each and eight intermediate panels of 6 feet 3 inches each. The panel points have been named as below :



2. *Dead Loads* :

(*i*) Uniform dead load per running foot of beam :—

(1) Top boom 2 feet 3 inches by 10 inches by 150 pounds
= 281 pounds.

(2) Uniform slab 3 feet 8½ inches by 7½ inches by 150 pounds
= 348 pounds.

(3) Asphalt 2 feet 7½ inches by 22 pounds = 58 pounds.

(4) Curb 1 foot 1 inch by 9 inches by 150 pounds.
= 122 pounds.
809 pounds.

(*ii*) Dead load of parapet on a 6 feet 3 inches panel :—

(5) Parapet without pilaster 6 feet 3 inches by 1·21 square feet by 150 pounds = 1,134 pounds.

(5*a*) Pilaster 0·69 square feet by 150 pounds = 104 pounds.

(6) Parapet with pilaster. = 1,238 pounds.

(*iii*) Dead load of 2 feet 10½ inches of Parapet without pilaster :—

(7) 2 feet 10½ inches by 1·21 square feet by 150 pounds = 522 pounds.

(*iv*) Dead load due to square slab—

(8) Reinforced cement concrete 12 feet 9 inches by 12 feet 9 inches by 7½ inches by 150 pounds = 15,241 pounds.

(9) Asphalt 12 feet 9 inches by 12 feet 9 inches by 22 pounds = 3,576 pounds.

18,817 pounds.

(*v*) Dead load due to half cross girders:—

(10) Between main girders 5 feet 9 inches by 1 foot by 1 foot 6 inches by 150 pounds = 1,294 pounds.

(11) Cantilever end 2 feet 1 inch by 1·1 square feet by 150 pounds. = 312 pounds.

1,606 pounds.

(*vi*) Weight of bottom boom per running foot.

(12) 2 feet 3 inches by 1 foot 5 inches by 150 pounds = 478 pounds

(*vii*) Weight of web per square foot

(13) 1 foot by 9 inches by 150 pounds. = 112·5 pounds

3. Panel loads due to dead load.

Point A.

(1) to (4) Uniform load 6 feet 3 inches by 809 pounds	= 5,056 pounds
(5) Parapet without pilaster	= 1,134 pounds
(12) Bottom boom 6 feet 3 inches by 478 pounds	= 2,988 pounds
(13) Web 11·45 square feet by 112·5 pounds	= 1,288 pounds
(8), (9) Square slab $\frac{18,817}{8}$ pounds	= 2,352 pounds
Total dead load at A	= 12,818 pounds
	= 12·8 kips.

Points B, B¹.

(1) to (4) Uniform load 6 feet 3 inches by 809 pounds	= 5,056 pounds
(6) Parapet with pilaster	= 1,238 pounds
(12) Bottom boom 6 feet 3¼ inches by 478 pounds	= 2,998 pounds
(13) Web 13·55 square feet by 112·5	= 1,524 pounds
(8), (9) Square slab $\frac{18,817}{8}$	= 2,352 pounds
Slab on cross girder $\frac{18,817}{4}$	= 4,704 pounds
(10), (11) Half cross girder and cantilever	= 1,606 pounds
Web pilaster 2 feet 2 inches by 1 foot 6 inches by 150 pounds	= 488 pounds
Total dead load at points B, B.¹	= 19,966 pounds
	= 20·0 kips.

Points C, C¹.

(1) to (4) Uniform load 6 feet 3 inches by 809 pounds = 5,056 pounds
(5) Parapet without pilaster = 1,131 pounds
(12) Bottom boom 6 foot 4½ inches by 478 pounds = 3,047 pounds
(13) Web 18·50 square feet by 112·5 = 2,081 pounds
(8), (9) Square slab $\frac{18,817}{8}$ = 2,352 pounds

Total dead load at points C, C¹. = 13,670 pounds
= 13·7 kips

Points D, D¹.

(1) to (4) Uniform load 6 feet 3 inches by 809 pounds = 5,056 pounds
(6) Parapet with pilaster = 1,238 pounds
(12) Bottom boom 6 feet 5½ inches by 478 = 3,087 pounds
(13) Web 26·8 square feet by 112·5 pounds = 3,015 pounds
(8), (9) Square slab $\frac{18,817}{8}$ = 2,352 pounds

Slab on cross girder $\frac{18,817}{4}$ = 4,704 pounds

(10), (11) Half cross girder and cantilever = 1,606 pounds
Web pilaster 4 feet 3½ inches by 1 foot 6 inches by 150 pounds = 966 pounds

Total dead load at points D, D¹. = 22,024 pounds
= 22·0 kips

Points E, E¹.

(1) to (4) Uniform load 6 feet by 809 pounds = 4,854 pounds
(5) Parapet without pilaster 6 feet by 1·21 square feet by 150 = 1,089 pounds
(12) Bottom boom 6 feet 4½ inches by 478 = 3,047 pounds
(13) Web 37·0 square feet by 112·5 pounds = 4,163 pounds
(8), (9) Square slab $\frac{18,817}{8}$ by $\frac{6 \text{ feet}}{6 \text{ feet } 3 \text{ inches}}$ = 2,258 pounds

Total dead load at points E, E¹. = 15,411 pounds
= 15·4 kips

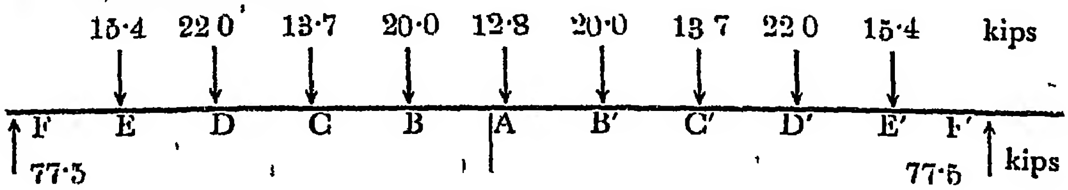
Points F, F¹.

(1) to (4) Uniform load 2 feet 10½ inches by 809 pounds = 2,326 pounds
(7) Parapet without pilaster = 522 pounds
(12) Bottom boom 3 feet 1 inch by 478 = 1,474 pounds
(13) Web 22·3 square feet by 112·5 = 2,509 pounds
(8) (9) Square slab $\frac{18,817}{8}$ by $\frac{2 \text{ feet } 10\frac{1}{2} \text{ inches}}{6 \text{ feet } 3 \text{ inches}}$ = 1,082 pounds

Slab on cross girder $\frac{18,817}{8}$ = 2.352 pounds

∴ Total dead load at points F, F^1, =10,263 pounds
= 10·3 kips.

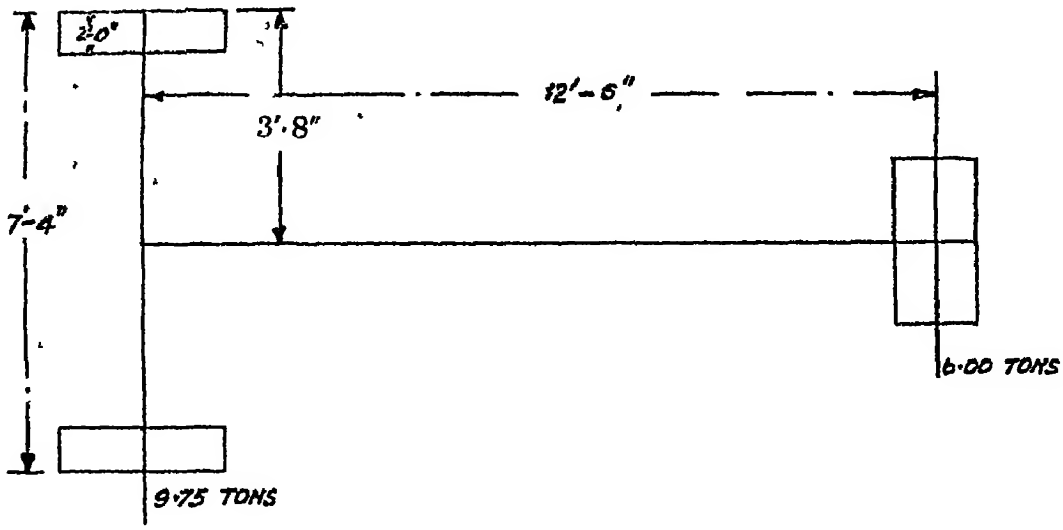
4. *Beam loads—Dead.*



5. *Beam loads : Super*

(*a*) Load due to crowd at 100 pounds per square foot
At points D, C, B, A, B^1, C^1 and D^1 6 feet 3 inches by 900 pounds =5·6 kips
At points E. E^1. 6 feet $7\frac{1}{2}$ inches by 900 pounds =6·0 kips

(*b*) Load due to a 15-ton roller in working trim
Distributed as below :—



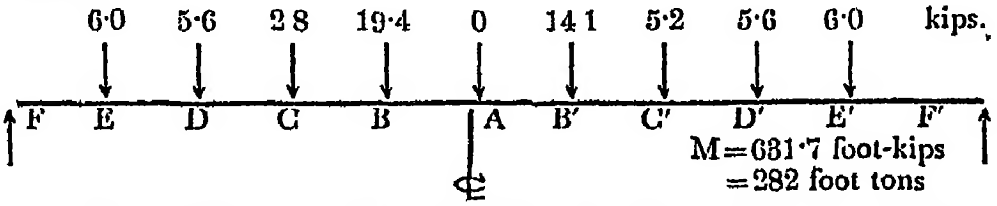
With the roller near the curb on one side of the road, maximum reactions on one main girder due to the roller are given by

$$\frac{12{\cdot}21}{13{\cdot}75} \text{ by } 9{\cdot}75 \text{ tons} = 19{,}400 \text{ pounds or } 19{\cdot}4 \text{ kips.}$$

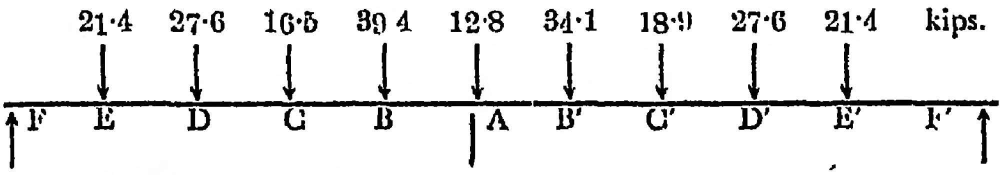
and $$\frac{12{\cdot}21}{13{\cdot}75} \text{ by } 6{\cdot}30 \text{ tons} = 12{,}900 \text{ pounds or } 12{\cdot}9 \text{ kips.}$$

With the centre of the roller at A, the two wheel loads will be at B. $B.^1$; there will be no crowd load in front of the roller up to the next panel-point C; similarly no crowd load for a length of 2 feet 3 inches behind the roller from B^1 towards C^1.

With the heavier load at B, the super loads on the beam will be as ıollows :



6. Total load on one beam : Dead and Super (roller at centre of Span).



7. *Cantilever : Dead loads.*

Point A. Half of beam load at point A= $\frac{12,818}{2}$ pounds 6,409 pounds

(10) (11) Half cross girder and cantilever	=1,606 pounds
(5a) Parapet pilaster	= 104 pounds
Web 1 foot 10 inches by 1 foot 6 inches by 1 foot by 150=	413 pounds
Total dead load at A	8,532 pounds
	=8·5 kips

Panel loads at B, C, D and E, are the same as beam dead loads at corresponding points.

The dead loads on the cantilever will be as follows :—

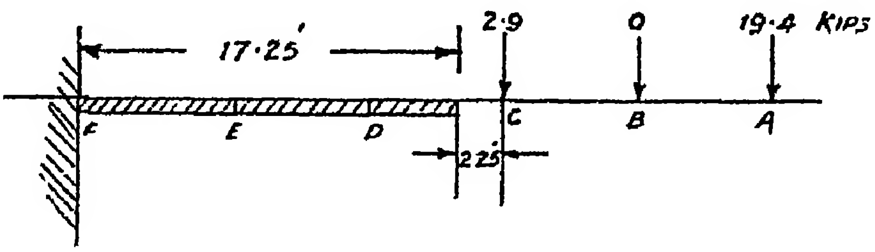
Bending moment at F =	15·4 kips by 7·0 feet	=107·8 foot kips
Plus	22·0 kips by 13·25 feet	=291·5 do.
„	13·7 kips by 19·50 feet	=267·2 do.
„	20·0 kips by 25·75 feet	=515·0 do.
„	8·5 kips by 32 00 feet	=272·0 do.
		1453·5 do.
	or	1,454 do.

8. *Cantilever : Crowd load of 100 pounds per square foot.*

Maximum bending moment due to crowd load=(100 by 9 by 32) by 16
=4,60,800 foot-pounds
or 461 foot-kips.

9. *Cantilever : Roller with heavier load at end and crowd load.*

The loads will be as follows :—

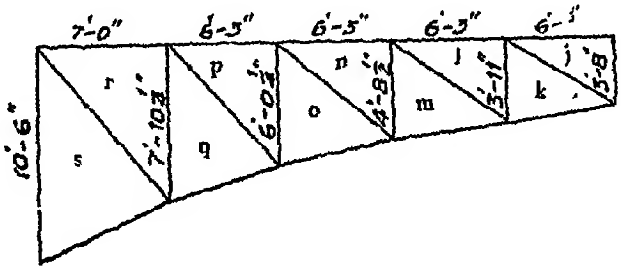


Crowd load = 17·25 × 900 = 15,525 pounds

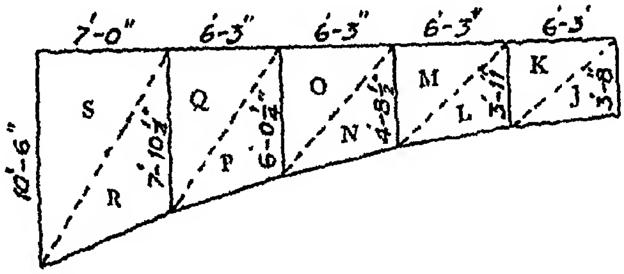
Maximum bending moment =	15,525 by 8·625	= 133,900
plus	12,900 by 19·5	= 251,850
"	19,400 by 32 0	= 620,800
		1,006,550 foot-pounds
		or 1007 foot-kips.

10. For the calculation of the stresses in the beam, the beam is assumed to consist of two framed systems as given below, each system taking half the total load on the beam.

(*a*) The full-line system (diagonals and verticals indicated by small letters).



(*b*) The dotted line system (diagonals and verticals indicated by capital letters).



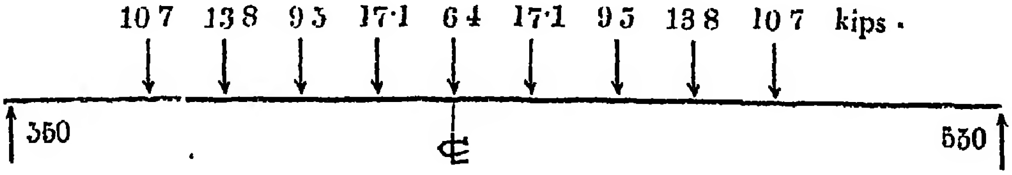
Stresses as produced in each system by half the total loads are calculated and added up to give the total stresses in the members. The same method is followed in the case of the cantilever. The notation in the two systems is shown on the frame diagrams on sheet No. 1.

11. Intermediate spans: Stresses in beam.

(*a*) The beam will have maximum bending moment with the roller at the centre and the cantilevers without any super load. The maximum moment in the cantilever due to dead load only is found in paragraph 7 to be 1,454 foot-kips.

In addition to half total loads on the beam as found in paragraph 6 each system will have to bear a bending moment at the support equal to half the maximum dead load moment in the cantilever or $\frac{1,454}{2} = 727$ foot-kips. With an arm of 10 feet 6 inches equal to length of the end vertical members each force in the couple will be equal to 69·2 kips.

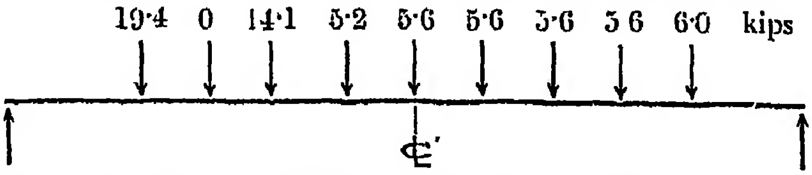
For maximum bending moment in the beam the loads on each system will therefore be as follows :



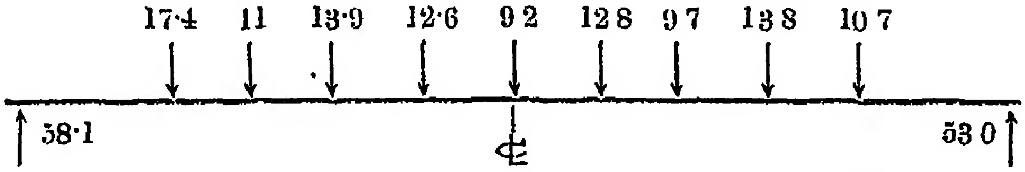
foot-kips

The stresses in the two systems are found in stress diagram on sheet No. 2 and tabulated in stress table for intermediate beams in sheet No. 5.

(b) For maximum shear in the beam, the heavier roller load will be at E, smaller at C and the cantilevers will have no super load. The super loads for this position due to roller and crowd will be as follows :



The moment due to cantilever dead load will, as in case (a) be 727 foot-kips at each support. Total half loads (dead load as per paragraph 4 and super as above) will therefore be as follows :



727 foot-kips 727 foot-kips

The stresses in the two systems are found in stress diagram on sheet No. 3 and tabulated in sheet No. 5.

(c) The worst hogging state of the beam will occur when the beam carries no super load, one cantilever is loaded with the roller at the free end with the crowd load on the remaining portion and the other cantilever carries a full crowd load only. Maximum moment in the cantilever due to dead load is found in paragraph 7 to be ... 1,454 foot-kips.

Maximum moment due to roller and crowd by paragraph 8 is ... 1,007 foot-kips

Total maximum bending moment in the first cantilever 2,461 foot-kips

Half bending moment to be carried by one system ... 1,231 foot-kips

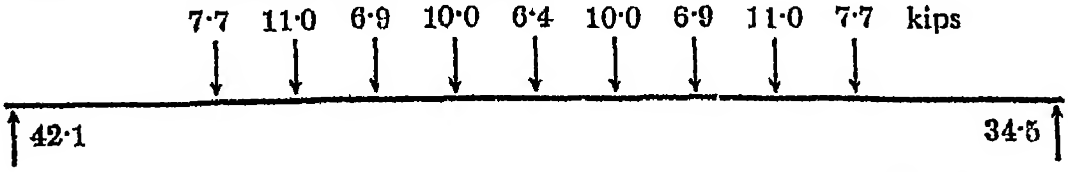
Maximum bending moment in cantilever due to dead load 1,454 foot-kips

" " " crowd load only as per paragraph 8 is ... 461 foot-kips

Total maximum bending moment in the other cantilever 1915 foot-kips

Half bending moment to be carrried by one system. ... 958 foot-kips

The forces acting on each system will therefore be as follows (half dead loads on beam as shown in paragraph 4) :



1,231 foot-kips 958 foot-kips

The stresses in the two systems are found in stress diagram on sheet No. 4 and tabulated in sheet No. 5.

12. *Intermediate Spans : Stresses in Beam (Contd).*

The stresses in the beam members as found in stress diagram on sheet Nos. 2 to 4 are given in table on sheet No. 5. Columns 12 and 13 give the absolute maximum compressive and tensile stresses occurring in any of the three methods of loading ; that is, the stresses for which the members are to be designed. Column 14 gives the sectional area of steel required for the maximum tension at 16,000 pounds per square inch. Columns 15 and 16 give the number and size of rods required and Columns 17 and 18 the number and size provided.

13. *Intermediate Spans.*

Compressive stresses in the bottom boom.

(*a*) The maximum compression force is 2,53,000 pounds in members

Sectional area of concrete 27 inches by 17 inches $= 459$ square inches.

Equivalent area of steel provided (four 1-inch diameter rods) 14 by 3·14 $= 44$ square inches.

Total equivalent area $= 503$ square inches.

Average compressive stress $= \frac{2,53,000}{503} = 503$ pounds per square inch.

Maximum intensity of compressive stress.

$503 \times \frac{53 \cdot 5}{45}$ $= 598$ pounds per square inch.

(*b*) Compressive force in the centre bay is 2,24,000 pounds.

Sectional area of concrete $= 459$ square inches.

Equivalent area of steel (Four 1-inch diameter and six 1⅜-inch diameter rods) $= 169$ square inches.

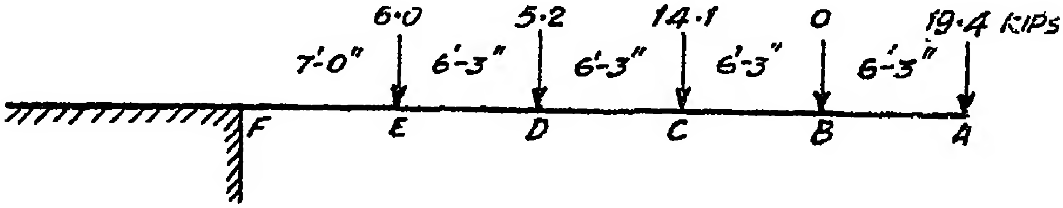
Total equivalent area $= 628$ square inches.

Therefore average stress intensity $\frac{2,24,000}{628} = 356$ pounds per square inch.

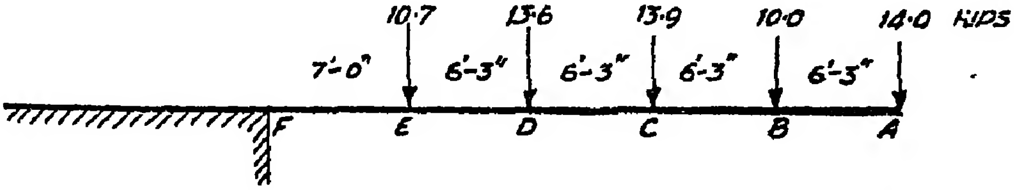
Maximum stress intensity 2 by 356 $= 712$ pounds per square inch.

14. *Intermediate spans : Cantilevers.*

Maximum bending and shear stresses will occur in the cantilever when the roller is on the cantilever with the heavier load at the free end and a crowd load occupies the rest of the cantilever Panel loads due to this super load will be as follows :—



The two framed systems taking half the total loads are shown in Frame Diagrams on sheet No. 6. Half total loads (consisting of dead loads as found in paragraph 7 and super loads as above) will be as follows :—

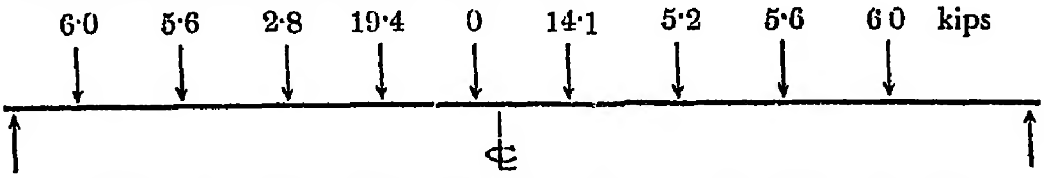


The stresses in the two systems are found in the stress diagram on sheet No. 7 and tabulated in sheet No. 8. Column 8 in the table on sheet No. 8 gives the area of steel required at 16,000 pounds per square inch for the maximum tensile stress in each member. Columns 9 and 10 give the number and size of rods required and Columns 11 and 12 the number and size of rods provided.

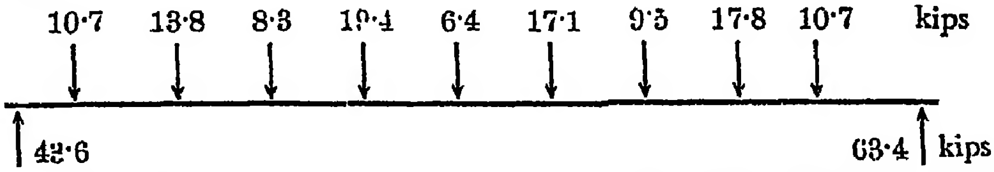
15. *End Spans : Stresses in beam.*

In the end spans the beams have to support a cantilever only at one end.

(*a*) Maximum bending moment will occur in the beam when the roller is at the centre of the span and the cantilever carries no super load. Moment at the support due to cantilever dead loads only is, according to paragraph 7, 1454 foot-kips. Each system will bear at one support a moment equal to half this moment or 727 foot-kips. The super loads on each beam will therefore be, as per paragraph 5, as below :—

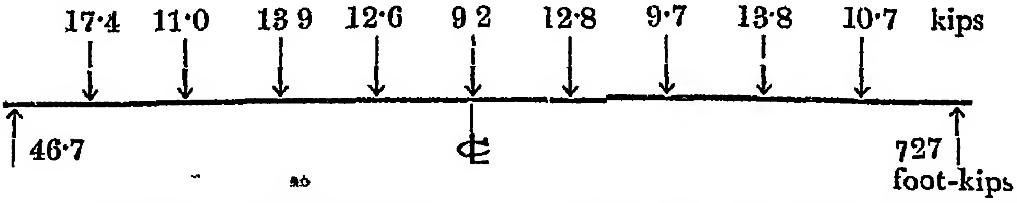


Adding to these loads the dead loads on the beam as given in paragraph 4 and halving the totals, each system will carry the following loads :—



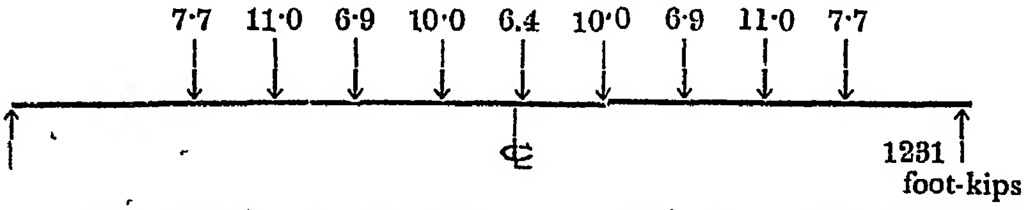
Stresses due to these loads are found in the stress diagram on sheet No. 9 and tabulated in sheet No. 12.

(*b*) For maximum shear, the loading will be as in paragraph 11(*b*) except that the moment due to cantilever dead loads will act only at one support. The loads carried by each system will therefore be as below :—



Stresses in the two systems due to these loads are found in the stress diagram on sheet No. 10 and tabulated in sheet No. 12.

(*c*) The worst hogging state of the beam will occur when the beam carries no super load and the cantilever carries the roller at the free end and a crowd load on the remaining portion. The moment at support in each system due to such loading in the cantilever is found in paragraph 11 (*c*) to be 1231 foot-kips. Taking half the dead loads on the beam as given in paragraph 4, each system will carry the following loads :—



The stresses in the two systems are found in the stress diagram on sheet No. 11 and tabulated in sheet No. 12.

16. End spans : Stresses in beam (contd.)

Details regarding the sectional area of steel required for maximum tensile stresses in the various members and the number and size of rods required and provided are given in table on sheet No. 12.

17. End spans.

Compressive stress in the top boom.

Maximum force is 353000 pounds near the centre.

Compression taken by the steel provided (six 1¼-inch diameter rods).

$$14 \text{ by } 7{\cdot}37 \text{ by } 600 \text{ by } \frac{15}{18} = 52000 \text{ pounds}$$

Therefore Compression taken by the slab $= 301000$ pounds

$$\text{Width of slab which takes this stress} = \frac{301000}{600 \text{ by } \frac{14{\cdot}25 \text{ by } 7{\cdot}5}{18}} = 24 \text{ inches}$$

18. End spans : Cantilevers

Type of loading for these cantilevers to produce maximum stress in the members are the same as that for cantilevers for the intermediate spans treated in paragraph 13 and the same design is provided.

Therefore horizontal pressure at E due to wind and flood is
7,900 plus 6,250 plus 1,525 = 15,675 or 15,700 pounds

Flood pressure on CD = (16·0 by 4·0) by 200 = 12,800 pounds

Components of this pressure at C and D are 6,400 pounds each

Therefore total horizontal pressure at D = 6,250 plus 6,400 = 12,650 or 12,700 pounds

Flood pressure on BC = (12 feet 4½ inches by 4 feet) by 200 = 9,900 pounds

Components of this pressure at B and C are 4,950 pounds each

Therefore total horizontal pressure at C = 6,400 plus 4,950 = 11,350 or 11,400 pounds

The horizontal forces due to wind and flood at F^1, F, D, C, and B are therefore

35,800, 4,900, 15,700, 12,700 and 11,400 pounds respectively.
These are shown at their points of application in the sketch.

3. *Overturning moments and extra loads on column sections.*

		Overturning moment.	*Arm.*	*Extra load due to overturning moment.*
About E.	35,800 by 12·5 =	448,000 foot pounds		
	4,900 by 11·2 =	55,000 ,, ,,		
	40,700	503,000	/ 13·75 feet	36,600 pounds
About D.	35,800 by 28·1 =	1,006,000		
	4,900 by 26·8 =	131,000		
	15,700 by 15·6 =	245,000		
	56,400	1,382,000	/ 16·33 feet	84,600 pounds
About C.	35,800 by 44·1 =	1,579,000		
	4,900 by 42·8 =	210,000		
	15,700 by 31·6 =	496,000		
	12,700 by 16·0 =	203,000	/ 19·0 feet	130,900 pounds
	69,100	2,488,000		
About B.	35,800 by 56·5 =	2,023,000		
	4,900 by 55·2 =	270,000		
	15,700 by 44·0 =	691,000		
	12,700 by 28·4 =	361,000		
	11,400 by 12·4 =	141,000		
	80,500	3,486,000	/ 21·08 feet	165,000 pounds

4. *Distorting moments in column sections.*

In ED 56,400 by 15·625 by $\frac{12}{4}$ = 2,640,000 inch-pounds

DC 69,100 by 16·00 by $\frac{12}{4}$ = 3,320,000 inch-pounds

CB 80,500 by 12·375 by $\frac{12}{4}$ = 2,990,000 inch-pounds

5. *Loads on column sections.*

a. Direct load on column cap as per para 1 = 288,900 pounds
Weight of column cap = 7,600 pounds
Half weight of brace E = 1,100 pounds
Weight of column DE = 27,300 pounds

Therefore direct load just above point D. 324,900 pounds
Extra load just above point D due to overturning moment as per para 3. = 81,600 pounds
Therefore Total load just above point D. = 408,300 pounds

b. Direct load at D = 324,900 pounds
Half weight of brace D = 6,200 pounds
Weight of column DC = 30,300 pounds

Therefore direct load just above point C = 361,100 pounds
Extra load just above C due to overturning moment = 130,900 pounds

Therefore total load just above point C = 492,300 pounds

c. Direct load at C = 361,400 pounds
Half weight of brace C = 7,500
Weight of column CB = 23,400
Therefore direct load just above point B = 392,300 pounds
Extra load just above B due to overturning moment = 165,400 pounds
Total load just above point B = 557,700 pounds

6. *Design of column sections.*

4 feet diameter column, reinforced with sixteen 1⅛-inch rods 2 inches concrete cover

Effective area = $\frac{\pi}{4}$ by 44^2 = 1,520 square inches

Equivalent area of Steel = 14 by 16 by 0·994 = 223
Total area = 1,743 square inches

Modulus of Section Z of concrete = $\frac{\pi}{4}$ by 22^3 = 8,359 inches^3

I of steel 21^2 = 441
$17{\cdot}8^2$ = 317
$11{\cdot}9^2$ = 142
$4{\cdot}1^2$ = 17

4 by 0·994 by 917 = 3646 inches^4

Equivalent $Z = \frac{3,616 \times 14}{21{\cdot}4}$ = 2385 inches^3

Therefore total Z = 8,359 plus 2,385 = 10,744 inches^3

Just above footing –

f (Direct) $= \frac{537,700}{1,743}$ = 320 pounds per square inch

f (Eccentric) $= \frac{2,990,000}{10,744}$ = 278 pounds per square inch

Therefore total stress at section = 598 pounds per square inch

Just above brace C.

f (Direct) = 492,200 = 282 pounds per square inch

f (Eccentric) $= \frac{3,320,000}{10,744}$ = 309 pounds per square inch

Therefore total stress at section. 591 pounds per square inch

Same section is adopted for portion DE.

7. *Braces.*

(*a*) Brace at C = 39 inches by 24 inches

Bending moment = 2,990,000 inch-pounds
plus 3,320,000
6,310,000 inch-pounds

Bending moment at end of brace = 6,310,000 by $\frac{7'\text{-}8''}{9'\text{-}6''}$ = 5,090,000 inch-pounds

Effective depth = 34 inches.

∴ Area of steel (at top and bottom) $= \frac{5,090,000}{34,16,000}$ = 9·36 square inches.

Use ten $1\frac{1}{8}$-inch rods giving 9·94 square inches.

(*b*) Brace at D.

Bending moment = 3,320,000 inch-pounds
plus = 2,640,000 inch-pounds
5,960,000 inch-pounds

Bending moment at end of brace = 5,960,000 by $\frac{6'\text{-}4''}{8'\text{-}2''}$ = 4,620,000 inch-pounds

Therefore area of steel (at top and bottom) $= \frac{4,620,000}{34 \text{ by } 16,000}$ = 8·49 square inches.

Use nine $1\frac{1}{8}$-inch rods giving 8·95 square inches.

8. *Column footings* :

(*a*) Side of footing $= \frac{7}{\sqrt{2} \text{ plus } 1}$ = 2·898 feet.

Area of footing $= 7^2 - 4 \text{ by } \frac{1}{2} \text{ by } \frac{(2\cdot898)^2}{2}$

$= 49 - 8\cdot4$

$= 40\cdot6$ square feet

$$\text{Volume of footing} = 40{\cdot}6 \text{ by } 2{\cdot}0 \text{ plus } \frac{40{\cdot}6 \text{ plus } 12{\cdot}6 \text{ by } 0{\cdot}5}{2}$$

$= 94{\cdot}5$ cubic feet

Weight of footing $= 94{\cdot}5$ by $150 = 1475$ pounds $= 6{\cdot}3$ tons

Load from column $= 577{,}700$ pounds $= 249{\cdot}0$ tons

Therefore total load $= 255{\cdot}3$ tons

$$\text{Therefore pressure on foundations } \frac{255{\cdot}3}{40{\cdot}6} = 6{\cdot}29 \text{ tons per square foot}$$

(*b*) For cantilever portion of the footing

weight for a 12-inch strip $= 6{\cdot}29$ by $1{\cdot}5$ $= 9{\cdot}44$ tons

Maximum bending moment $= 9{\cdot}44$ by $0{\cdot}77$ $= 7{\cdot}27$ foot tons

$$\text{Therefore area of steel required} = \frac{7{\cdot}27 \text{ by } 12 \text{ by } 2{,}240}{21 \text{ by } 16{,}000} = 0{\cdot}60 \text{ square inch}$$

Steel for 7 feet width $= 7$ by $\cdot 60$ $= 4{\cdot}20$ square inches

Use six $1\frac{1}{8}$-inch rods giving $5{\cdot}96$ square inches

II. *Trestles with Foundation at R. L.* 1337.

These are designed similarly, the corresponding results being as follows :—

1. Horizontal forces due to wind and flood at F', F, E, D and C are 35,800 ; 4,900 ; 17,100 ; 15,000 and 17,500 pounds respectively.
2. Overturning moment about E, D', C' and B are 503,000 ; 1,404,000 ; 2,598,000 and 4,495,000 in pounds.
   Arms of moment 13·75, 16·33, 19·00, 22·5 feet
   and extra loads due to this moment
   36,600 ; 86,000 ; 136,700 ; 199,800 pounds.
3. Distorting moments in FE, ED', D'C' and C'B'
   1,500,000 ; 2,700,000 ; 3,500,000 and 5,690,000 inch-pounds

(*c*) Total loads (direct plus extra due to overturning moments) just above

D'	C'	B'	are
422,400	521,100	647,050	pounds.

(*d*) Equivalent total area of column section : 2402 square inches

Equivalent total Z of column section : 17,739 inches^3

Just above footing f (direct) = 269 pounds per square inch

Just above footing f (eccentric) = 328 pounds per square inch

Total maximum stress = 597 pounds per square inch

(*e*) Moments to be provided for in braces C', D', and E are 7,150,000 6,280,000 2,880,000 inch-pounds

Area of steel required 10·4, 8·1 and 7·2 square inches

Area of steel provided 11·0, 8·6 and 7·4 square inches

(*f*) Area of footing $= 53{\cdot}0$ square feet

Total load on footing $= 296{\cdot}9$ tons

Pressure on foundations $= 5{\cdot}60$ tons per square foot

Area of steel required $= 7{\cdot}76$ square inches

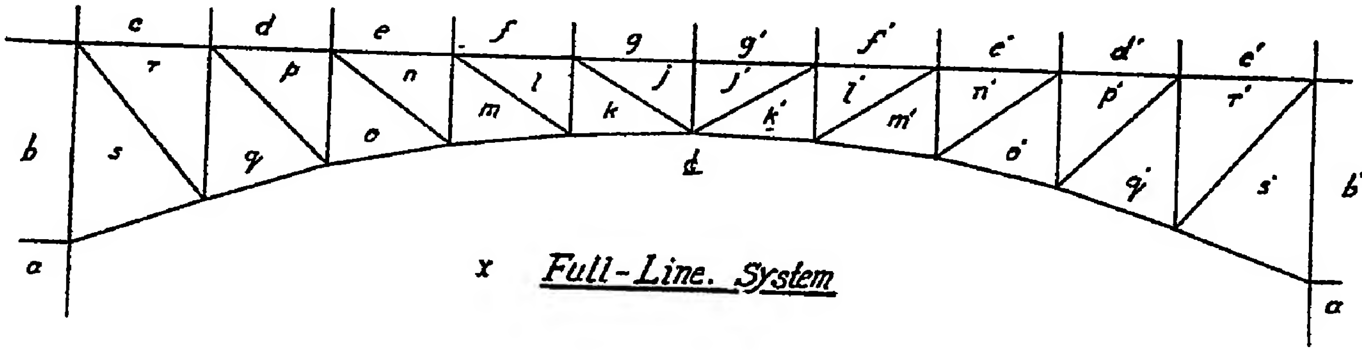
Area of steel provided $= 7{\cdot}95$ square inches

Sheet No. 1

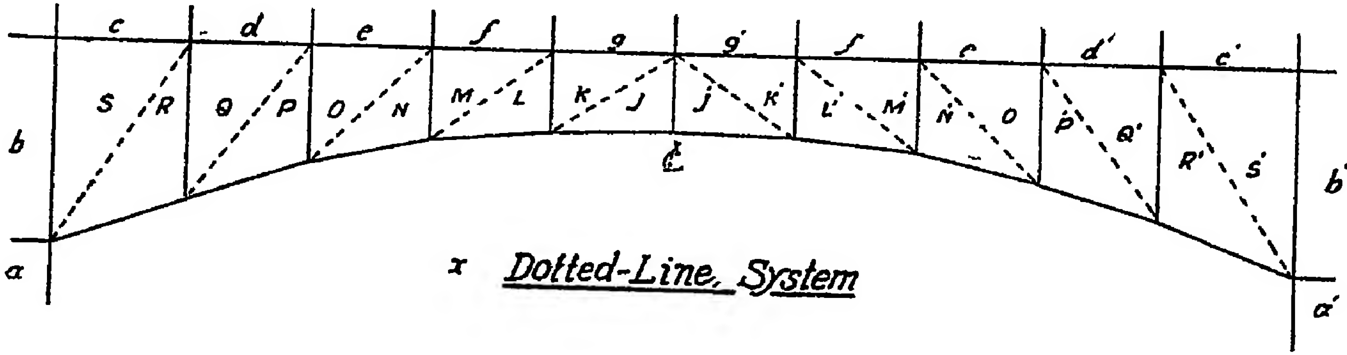
Shahgadh Bridge Superstructure

Main Girders Frame Diagrams for Beams

Scale 1 inch = 12 feet



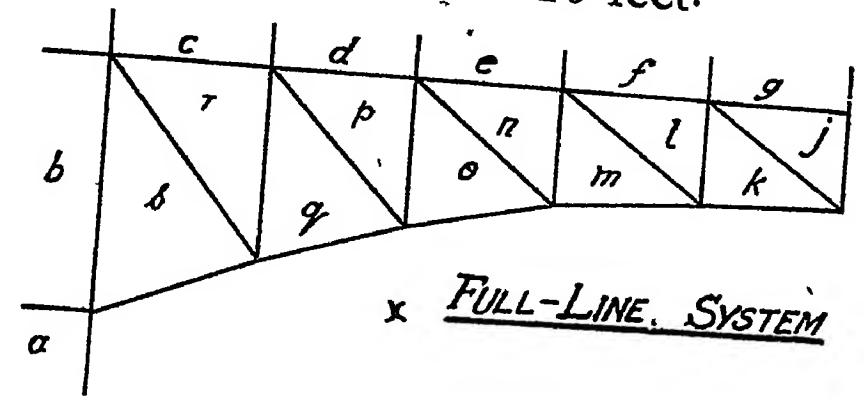
x Full-Line. System



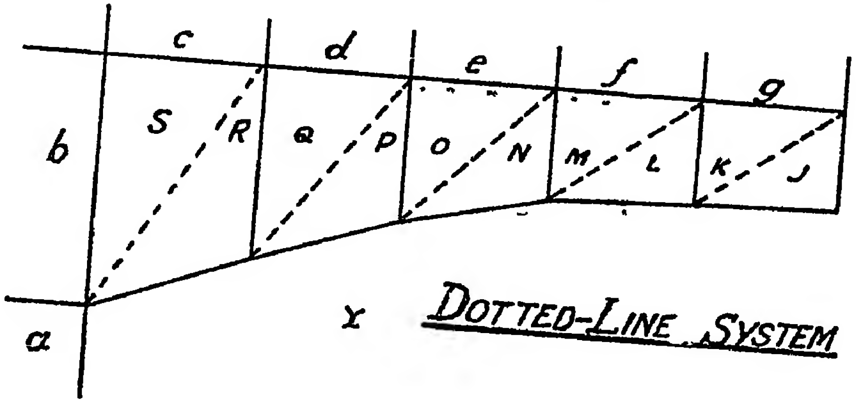
x Dotted-Line. System

Sheet No. 6.

Shahgadh Bridge: Superstructure
Main Girders Frame Diagrams for Cantilevers.
Scale 1 inch = 10 feet.



FULL-LINE SYSTEM



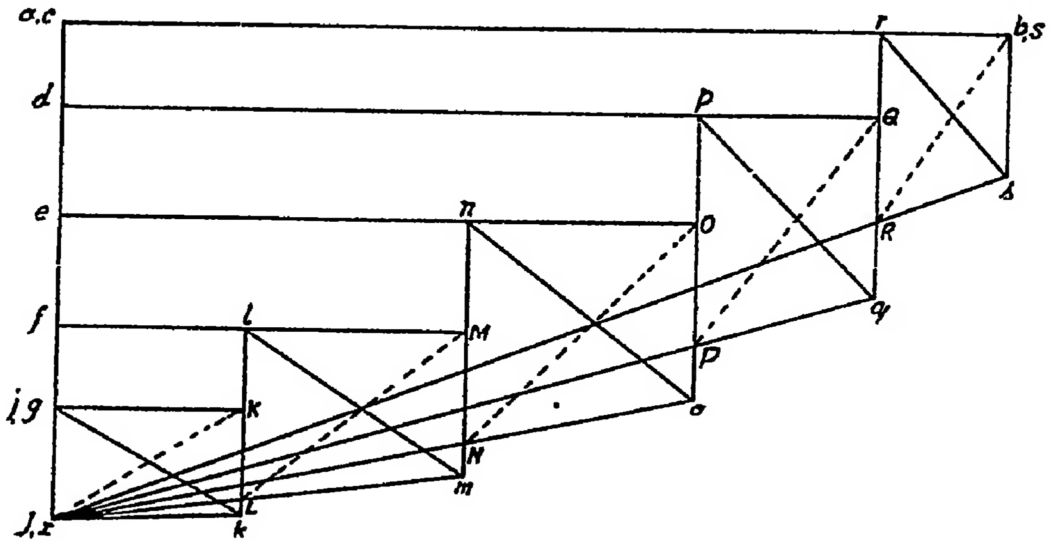
DOTTED-LINE SYSTEM

Sheet No. 7.

Shahgadh Bridge: Superstructure

Intermediate Spans: Stresses in Cantilevers.

Scale 1 inch = 2,820 Pounds.



Loads—Crowd with Roller at Free End.

Discussions on Paper No. D.

Mr. Dildar Hussain (Author): I may say for the information of the members that the illustration which has appeared along with the paper might give them an idea that the bridge is one with continuous arches. This is not so. Each section consists of a span with a continuous beam 64 feet centre to centre in two cantilevers 32 feet each Between each unit, there is a space of 1 foot to serve as an expansion joint.

Mr. J. C. Guha (Bengal): Water cement ratio is one of the vital points in important constructions of cement concrete, as an excess of even 10 to 15 per cent of water causes a decrease of strength of about 50 per cent. Similarly too little water is equally harmful. The question is whether the quantity of water actually required per bag of cement should be specified beforehand and followed throughout the construction. The quantity of water required should be governed by (1) the condition of workability of the concrete, (2) the size, grading and condition of the aggregates, and (3) brand of cement used. In any case, the normal consistency of the mixture requiring the use of a certain quantity of water per bag of cement is usually, at least should be, determined by some mechanical tests, such as slump test. Even for the same stuff and same proportions of meterials used, no definite quantity of water per bag of cement may be specified for adoption throughout a construction. In actual practice, it was found that according to variations of temperature at different hours of the same day different quantities of water were required per bag of cement.

In the construction of the cement concrete road on the Calcutta-Jessore Road, Kutni cement, clean Barakar sand and Pakur stone aggregates were used in the proportion of 1 : 2 : 4. Ballast was wet before use. Sand was dry. In that work, a slump of about 2 inches in a freshly moulded mix in a 12 inches long truncated metal cone 4 inches and 8 inches diameters upon withdrawing the form by a steady upward pull gave the mixture of proper and workable consistency. Concrete was mixed in a mixer. It was observed that at about 8 a.m. when the work would be usually commenced, about 4¼ gallons of water per bag of cement were necessary : at about 1 p.m. as much as 5 gallons of water were necessary, to get the proper consistency by slump test.

The whole idea of my remark is that in big and important construction of cement concrete, it might not be proper to stick to any definite quantity of water per bag of cement throughout a certain construction, but some sort of mechanical tests should be carried out frequently to arrive at the required quantity of water, as it may vary under different conditions for the same materials and same proportions.

Mr. W. L. Murrell (Bihar): The road development programme in the Chota Nagpur Circle, Bihar, includes the construction of a number of bridges of considerable size and importance and, in consequence, it has been necessary to make a careful study of local conditions and of the generally accepted formulae for the calculation of peak discharge.

Search through the publications of the Institution of Civil Engineers showed that considerable assistance was available as to Indian conditions in Volume CCXVII of the Minutes of Proceedings, and in the Journals for March and October, 1937.

By raising discussion on Mr. Dildar Hussain's very interesting paper, I hope to gain further information on the question of peak discharge.

My first point is that the paper states that a peak discharge may be calculated from Dicken's Formula $D=CM^{\frac{3}{4}}$ " where the value of C varies from 150 to 1,000."

According to Colonel Hearn, page 269 of the Minutes referred to, the coefficient C is taken as 1,000 to 1,400 in the Central Provinces, and 1,600 in the Western Deccan.

On page 288 of the Minutes, Colonel Hearn shows definitely and clearly that the real Dicken's coefficient C based on catchments from 1/80th square mile to 27,000 square miles, is 825.

Now, what on earth is the use of a formula for peak discharge when different authorities in India use co-efficients varying from 150 to 1,600 ?

It is not very economical to construct a bridge capable of passing 11 times as much flood water as may actually occur and it might not be helpful to one's career to construct a culvert which was overtopped by the first Christmas rain !

This brings us to the formula $D=C.M^{0.80-\frac{1}{14}\log M}$ where C = constant, "1550 in this case." This is known as the " Chief Engineer's " formula, and it has been used for the calculation of the peak discharge in the case of the bridge under discussion.

It seems to be an improvement on Dicken's formula as it brings in the principle that maximum intensity of precipitation is a logarithmic function of the magnature of the area under discussion.

There is insufficient time in the Congress for anyone to put up a note explaining the evolution or development of this formula, so perhaps this could be done as subsequent correspondence to be printed with our Proceedings.

But the Chief Engineer's formula belongs to the same family as that of Colonel Dickens and the words of Mr. Hussain " 2,550 *in this case* " show that it has the same family failing of a variable constant.

I therefore now make a plea for the Indian Roads Congress to issue something authoritative to assist us in such problems—say a printed sheet or two which we could stick in the back of our recently issued Standard Specification and Codes of Practice for Road Bridges in India.

My own inclination is to follow Lillie, *vide* page 295 of the Volume CCXVII referred to, which takes into account also the shape and general slope of the catchment, the annual rainfall, and general character of the ground.

What we need is a series of curves, such as those given on pages 461 and 462 of the Journal for October, 1937, for different parts of India with a brief description of how the curves are arrived at, so that we can understand our own calculations and not be accused of applying a formula we do not understand.

One other point about this very interesting paper. We do not have much in the way of design calculations or working detail, and this introduces a rather delicate matter requiring tact, which I now approach in the method of a bull approaching a gate.

Mr. Hussain states that the bridge was designed and constructed by a certain firm of engineering contractors.

I submit that the contractors do not deserve quite all the publicity that this paper gives them, as we have not had the opportunity of looking into their design and working details.

As a critic, I say that the author is incorrect in mentioning the name of the contractors. As a fellow-engineer, I say that I would have made exactly the same mistake.

Here, again, the Indian Roads Congress might very usefully suggest the lines on which such papers as this should be written.

Such procedure would also assist us to compare one bridging project with another.

Mr. S. Srinivasa Raghavacharyar (Trichinopoly) : I have a few points of doubt to be cleared. Are piles designed to prevent distortion ? Are there crossgirders ? Why can we not have direct thicker slabs and dispense with the cross girders completely ? In the plan attached to the paper the cross section of the girders is not found. Will the author please explain these points ? The piles are designed to stand only wind pressure, but they should also stand the pressure of water.

Mr. N. Durrani (Bobbili) : This particular river is bridged in as many as six places including Shahgadh. I request the writer of this paper may give the mileage along the length of the river as this, along with the hydraulic particulars given for each bridge, will be useful to give an idea about the country forming the basin of the river. This information will be very useful for arriving at waterways at any other crossing of the river particularly in between any of the existing ones The writer has referred to the Chief Engineer's (Alinawaz Jung's) formula and one or two speakers have touched it. The writer will do well to give full details as to how the formula was originally derived and its advantages over any of the classic formulæ.

The details of expansion joint have not been shown in the drawings Sand mixed with tar or hemp steeped in tar works well for wearing coats of cement concrete but it will not be efficient for decks. Elexiod joints are good which can be fixed in multifarious ways.

My experience tells me that wearing coat with ¼-inch tell-tale rods at 1 foot 6 inches centres works as a good binder for the concrete and during wear the appearance of tell-tale grill will be a warning for a recoat.

In the paper it is stated that impact allowance has not been made because in the design stresses of 600 pounds and 16,000 pounds have been taken for concrete and steel respectively, as against 750 pounds and 18,000 pounds. The nature of workmanship demanded in the latter case is far superior than in the former. Even assuming that superior workmanship is ensured it is good to design with these stresses and actually allow for impact rather than working at low stresses and expect impact to adjust itself.

Regarding percentage of water to be used with cement concrete, no doubt excess water weakens the concrete but shortage honeycombs it. The latter is dangerous and must be strictly avoided, even by using a little excess of water. After one or two mixes it will be possible to arrive at a proper quantity of water for a batch mix that ensures complete absence of honeycombing with just a wee bit excess water as a safeguard against shortage and the resultant honeycomb concrete.

Rao Sahib M. A. Rangaswami (Bihar): The point I wanted to raise about the discharge formula adopted in this case has been dealt with by Mr. W. L. Murrell. One or two points I would like to know from the author. By adopting this design was any susbstantial reduction in cost made as compared with the ordinary reinforced concrete and arch design ? Secondly I should like to know how the spaces between cantilevers are filled up and also what safeguards are taken to prevent the lateral movement of any one span area. In an earthquake area such a possibility is almost certain. Mr. Murrell suggests that undue prominence is given

to the designers. I think there is no harm in furnishing the name of the designer.

Mr. W. L. Murrell (Bihar) : What I wanted to say was that no firm's name should be mentioned unless they give this Congress details of design.

If such details are given, it is important that the name of the firm should be stated. We are all on the lookout for reliable firms from whom to invite designs and tenders.

Rai Bahadur S. N. Bhaduri (Chairman): Some members have complained about the lack of details in the paper. The details were sent in but were not printed.

Mr. L. B. Gilbert (Government of India): The details were received but too late for publication.*

Rai Bahadur S. N. Bhaduri (Chairman): Will Mr. Dildar Hussain now reply.

Mr. Dildar Hussain (Author): Mr. Guha has offered his remarks advocating the use of slump tests on large works. He states that on the Calcutta Jessore Cement Concrete Road the quantity of water used varied from 4½ gallons in the morning to 5 gallons at noon and 4½ in the evening. With regard to the slump testing, opinions of those who have done reinforced cement concrete works differ. Mr. Mearce, C.E., of Messrs. John Gammon & Co., has stated on his experience of Bombay practice that the results obtained from slump testing were found to be so inconsistent and variable as to prevent him from placing much reliance on this method. The author also holds the same views based on his experience of numerous reinforced cement concrete works carried out on the Nizamsagar Canal. Perhaps for the use of cement concrete in road works where the mix is not supposed to perform any functions similar to what is required in the case of reinforced structures. Slump testing may be helpful in giving uniformity for the regulated quantity of the mix which has to be laid in fairly thin layers. In the case of reinforced cement concrete bridges where the depth of members is large and the reinforced fabric is complicated, the mix must have the necessary workability. This becomes largely a matter of judgment. The amount of water found necessary for obtaining the requisite workability has to be determined with reference to the character of the materials and the water control on the mixer has to be set accordingly.

Mr. Harrington Hudson refers to the standardization proposed by Mr. Lloyd on the proportion of water to be used for any desired consistency of concrete. But, here also, the recommendations are hedged in with so many qualifications that judgment has to come into play again and the quantity of water does not remain amenable to mathematical precision. The principal fact that has to be borne in mind by the concrete engineers is that the water cement ratio should be kept as low as possible to avoid the loss of strength, liability to shrinking and cracking and other evils resulting from the excessive use of water.

Mr. Murrell had some remarks about the formula for the discharge. The question of determining a formula for the maximum flow off catchment areas of different sizes had been under consideration for some time. There is no point connected with hydraulic engineering on a large scale which calls for more enquiry on the part of the engineer than this, as upon it depends primarily the design of any work contemplated in connection

* These have been printed *vide* Appendix to the paper,

with drainage, or the disposal of surplus floods, and an error in one direction means unnecessary expenditure, while an error in the other direction may mean disaster.

The most convenient formula is of the form $D = C M^x$ where M is the size of the drainage area in square miles, C a numerical co-efficient depending on the physical, geological and climatic conditions of the drainage area, while x is an exponent the value of which is less than unity. There are many formulæ of this type in use but they suffer from the drawback in that they give a constant value to the exponent. Fanning had suggested the ratio of 5/6, Dickens 3/4, Major Ryves 2/3, and Lieut-Col. O'Connel 1/2.

None of these can be said to be rational. as very often wide differences in results have been noticed in their use. In order to adjust these resulting differences recourse is often had to variation in the value of C, and those who use these formulæ apparently take it that the value of C is an average for all sizes of catchments.

Giving x a constant value less than unity certainly means that a larger area will have a proportionately less discharge than a smaller one; but it also means that the proportion between the rates of discharges remains the same for the same proportion between drainage areas, irrespective of their sizes. The former is correct but the latter is not true. It can unhesitatingly be said that the proportion of maximum flood from a drainage area of 1,000 square miles is considerably greater. Adherence to a constant value for x must, therefore, give rise to great uncertainty in the use of the formulæ.

What is required is to ascertain the law governing the maximum discharge from drainage areas of different sizes, under the influence of meteorological, topographical and geological conditions. The value of C is the modulus for a particular locality and converts the relation of the size of the catchment into the figures for the discharge. x must be regarded as the classifier and it should be a function of M.

In Bombay practice, curves of Whiting and Beal are used and are said to be reliable for the areas up to 1,000 and 1,600 square miles. Both the formulæ yield a curve up to 100 square miles and a straight line beyond 100 to 1,000. We have no knowledge about the using of the formulæ beyond those limits.

A value of C in Dicken's formula between 150 and 1,000 was given by Strange in his book on Roads and Bridges. But taking the formula $D=CM^{\frac{3}{4}}$ and assuming that $M=1$, $D=C$ and therefore if $C=150$ it will mean that $D=150$ cusecs, which is incorrect.

It can be shown that the value of C in Dicken's formula varies from 244 to 669. In the case of the bridge at Nanded which is built about 150 feet below the Shahgadh bridge, the catchment area is 19,000 square miles. The discharge is 563,000 cusecs. On the Godavari bridge at Sone, which is the biggest bridge in the Nizam's Dominions, the catchment area is 43,000 square miles and the discharge is 730,000 cusecs. This gives a value of C in Dicken's formula: 244. The bridge at Bhima at Yadgir has got a catchment area 25,488 square miles with a discharge of 659,000 cusecs. This gives the value of C in Dickens: 669. In the case of the bridge across the Kistna River now under construction in the Raichur District, the catchment area is 49,500 square miles and the discharge is 979,910 cusecs. This gives a value of C in Dicken's formula: 275, the equivalent value of C of Chief Engineer's formula being 1910.

The differences in the discharges show that the conditions of different catchments are so different that, with the limited data before us, it is not possible to fix the value of C good enough for universal application.

The Chief Engineer's formula $D = C\,M^{a - b \log M}$ implies that—

(1) the discharge will have to go on increasing until $\log M_1 = \frac{a}{2b}$ and then will begin to fall

(2) the maximum rate of discharge will occur when $\log M_2 = \frac{a-1}{2b}$

(3) $\log M_1 - \log M_2 = \frac{1}{2b}$

This means that the values of a and b have to be fixed with reference to the various considerations. The values as given to a, b, and C in the Chief Engineer's formula are based on some of the observed maximum discharges.

It would be reasonable to assume that there is a limit to the value of M beyond which there will perhaps be no appreciable increase in the flow due to the moderating influence of the extent of the drainage area.

With regard to the objection that provision of extra waterway entails extra money and the changes of a flood may not occur for once in fifty years or even hundred years, it may be said that a large factor of safety has to be provided in the case of engineering structures, for it may happen that the very first year after construction might be the year of maximum flood.

In the case of the Patalganga bridge recently constructed in the Bombay Presidency, according to Beal's curve the discharge to be provided was 65,000 cusecs. In actual design, Inglis' formula was adopted giving a discharge of 87,000 cusecs. This corresponds to Chief Engineer's formula to $1{,}700\,M^{0 \cdot 92 - \frac{1}{14} \log M}$.

I will next come to Mr. Durrani's enquiry regarding expansion joint. The expansion joint consists of sand and tar filling, but the latest information is that this filling is not working quite satisfactorily and it might be necessary very soon to introduce T-iron and lay over it the bituminous covering.

Lastly, with regard to giving publicity to the name of the engineering firm, I may point out that in a previous session of the Congress, Rai Bahadur S. N. Bhaduri in his paper on the Parbati bridge on the Bombay-Agra Road had mentioned the name of the firm and the Chief Engineer of the firm. In the papers of this session "Dhakuria Lake bridge" there is the specific mention of the name of the firm responsible for the design of the Dhakuria Lake bridge. In making a mention of the name of the firm in my paper, I only followed the beaten track of the engineers.

Rai Bahadur S. N. Bhaduri (Chairman): I thank Mr. Dildar Hussain for the very interesting paper presented by him and the discussion on it. I would suggest that the Congress may take up the question of flood discharges in the different provinces and States and issue a code of practice for the same.

We shall now disperse and meet again at 2-30 p.m.

Mr. S. G. Stubbs (President): I have pleasure in proposing a vote

of thanks to Rai Bahadur S. N. Bhaduri who has occupied the chair for the discussion of this group of papers (*acclamation*).

The Congress adjourned for the luncheon interval at this stage.

CORRESPONDENCE.

I.—Comments made by Mr. K. S. Raghavachary, Assistant to the Special Engineer, Road Development, Madras, by post on Paper No. D.

1. The several factors taken into consideration for the adoption of trestle type for this bridge may be furnished, especially in the present case where rocky foundations are met with at depths ranging from 5 feet to 25 feet and the rocks have been actually chiselled and benched to seat the trestles. Where open foundations are possible and rock is met with at reasonable depth, solid masonry piers and abutments would ordinarily be cheaper. The trestle bridges are generally adopted in cases where good foundations are not available even at great depths.

2. For the loading of a 15-ton steam road roller, the 7½ inches depth of slab adopted seems to be insufficient for a span of 13 feet 8 inches.

3. Comparative costs of the bridge with T-beams or bow-string girders may also be worked out, as the cost as per present design works out to Rs. 567 per running foot.

4. In the case of bridges of the sizes considered, it is usual to consider the comparative costs of the bridges with different spans, to decide on the economical span. I wish to know whether this aspect has been considered, especially when several bridges have been constructed in the State, and some more are under consideration.

II.—Reply by author (Mr. Dildar Hussain) to the comments made by Mr. K S. Raghavachary on Paper No. D by post.

1. The reasons for adopting the trestle type of bridge against a bridge with masonry piers and abutments, are that stone suitable for masonry is not available near the site of the bridge, the nearest quarry being about 8 miles away. Hence it was considered cheaper to adopt the reinforced Cement Concrete bridge, the design as constructed being found more economical than others.

2. Calculations are given with the paper.

3. This is not possible now. It might be a useful exercise of an academic interest.

4. This is a subject with wide issues. In the Deccan where good foundations are generally met with and stone of good quality is available it seems preferable to adopt masonry bridges since use is made of all local materials. It has been found, that taking different aspects into consideration, 60-feet span is about the limit where masonry arches are economical as compared with other types. Almost all larger bridges in the State, such as those constructed on the Godavari, the Manjra, the Bhima and the Krishna have been constructed with 60-feet arches.

Paper F.

The congress reassembled at the Osmania University Hall at 3 p.m. after the luncheon interval and Mr. L. B. Gilbert took the chair.

Mr. L. B. Gilbert (Chairman): I call upon Rai Sahib Fateh Chand to present his Paper on " Roads under Local Bodies and how to maintain them."

The following paper was then taken as read :—

PAPER No. (F).

ROADS UNDER LOCAL BODIES AND HOW TO MAINTAIN THEM.

By

RAI SAHIB FATEH CHAND, SECRETARY-ENGINEER, DISTRICT BOARD, BIJNOR AND PRESIDENT, DISTRICT BOARD ENGINEERS' ASSOCIATION, UNITED PROVINCES.

Classes of Roads.—The roads under Local Bodies may be divided into two classes :—

(1) Unmetalled roads.

(2) Metalled roads.

2. *Ratio of Different Classes of Roads.*—The majority of the milage under Local Boards consists of unmetalled roads. In an average district of the United Provinces the ratio of metalled roads to those unmetalled will be found to be 1 to 4 and in some 1 to 7 or even less than that.

3. *Importance of Unmetalled Roads.*—With the advent of motor lorries, increased value of time, more education, higher standard of living, increased railway facilities, better marketing facilities, and other activities promoting travel, the importance of unmetalled roads has very greatly increased during the past few years, and it is now impossible for the District or Local Boards to ignore the maintenance of their unmetalled roads. Limited funds mean that there can be only a few metalled roads in each district. The future development of the country both politically and economically must, therefore, depend mostly on unmetalled communications. Considering the great length and importance of unmetalled milage both at the present time as well as in the near future, I shall deal mostly with these roads in this brief note using only a small space for metalled roads.

4. *Selected and Unselected Roads.*—For purposes of maintenance, the unmetalled roads should be divided into (1) selected roads and (2) unselected roads according to the importance of each road and the nature of traffic over it.

5. *Allotment of Funds.*—There should be a regular allotment of funds for (1) the construction of bridges, culverts, causeways and other original works, and (2) annual maintenance of the roads, bridges and culverts. It will often be found difficult to secure the necessary funds for either. In 1914 the main heads of District Boards expenditure in the United Provinces were standardized and the amount to be provided by the Boards in their budgets for metalled and unmetalled roads respectively as also the number of public works subordinates required to be employed by each Board to maintain the latter kinds of roads only (the former ones then being under the control of the P. W. D.) was given in the Government orders on the subject. But these allotments were not obligatory and were not always forthcoming with the result that inspite of increased traffic and the importance of these roads and of the increased cost of maintenance

per mile as compared to 1914, the allotment for unmetalled roads has been cut down by more than 75 per cent in some districts and by more than 60 per cent on the average for the whole of the Province. In fact, as has been mentioned in some of the Government reviews on the administration of Local Boards, the allotment for unmetalled roads has been the first to be curtailed when funds were required for any new expenditure. One way to put a stop to any further decrease is to have a minimum allotment fixed for roads as has been done in the case of Education. The funds available should be distributed per mile for selected and unselected roads respectively.

6. *Raising of Low Portions.*—The improvements generally necessary consist of:—

1. Raising of portions that are depressed, where water stagnates during the rains and for some time after. The portions where bridges or culverts are to be constructed should be left out. These should be raised after the bridges or culverts have been built, but in the meantime, the road on either side can and should be raised and a ramp made on the site of the bridge with a slope of 1 in 30 to pass the cross drainage. This will reduce the inconvenience of wading through a length of miles and furlongs full of water to a few yards only or in the case of the larger *nalas* to a few hundred yards only. The raising should be at least one foot above usual flood level, otherwise whatever earth is put in is sure to be washed away and money spent on insufficient earth-work will not only be a waste, but will cause a great hardship to traffic due to soft earth below water level forming a quagmire during the rains. The earth-work should be done immediately after the rains where earth is available, but mostly it has to and should be done in summer so that the earth will be consolidated during the winter rains in the former case and by the monsoon in the latter case. The clods should be properly broken in the borrow pits before earth is taken to the road. The borrow pits should be of a given shape and size with regular *tattis* and *motams* so that the contractor does not take advantage of the old pits or natural depressions or small drains made by cultivators to raise the boundaries of their fields.

The borrow pits should be so arranged at the extreme boundaries of the road, that after the removal of *tattis* and *motams*, they would serve as drains to take off water to the natural slope which might be a *nala* or a pool of water or natural slope of ground. Unnecessary raising should be strictly avoided as the road level is the best where it consists of natural ground level. Twenty feet width of road should usually suffice. In the case of unimportant roads it can be reduced to 15 feet. The side drains should be cleaned annually after rains and all the ruts and rain cuts should be filled up with the earth thus obtained. All the portions required to be raised on each road should be measured and it should be calculated in how many years time the road would be raised completely. This will help the engineer in securing funds more easily.

It is important that the measurement of earth-work must be made and closed finally before the rains set in. In fact, the subordinate should take measurements at every inspection before the rains.

7. *Construction of Bridges and Culverts.*—The next improvement consists of construction of necessary bridges, culverts and causeways. The worst portions should be taken up first and of these the portions requiring smaller culverts should find precedence over others. A regular programme

should be prepared coterminous with the term of the Board as suggested for the raising of the depressed portions. The usual mistake of making these bridges or culverts too high or too wide should be avoided. Fourteen to eighteen feet width for selected and ten to twelve feet width for unselected roads where only a few carts pass during the course of twenty-four hours, should usually suffice. Where funds cannot be made available for proper sized bridges, it is usually of great help to construct causeways of 10 to 13 feet width with or without a small central opening consisting of a Reinforced Concrete slab or Hume Reinforced Concrete pipes.

8. *Proper Drainage.*—The next item in order of importance is the improvement of drainage system. The construction of a small drain at the boundary of the road often mitigates many troubles. What often happens is that instead of crossing the road at the lowest point only water crosses the road at several points unnecessarily.

The raising of the road automatically puts a stop to such cross drainage in most cases. But when it does not, this result should be secured by the construction of a small drain at the extreme boundary of the road. The drain should be made with outlet to a natural depression and the water of the road should be made to come to this drain instead of flowing longitudinally along the cart ruts or at any other point it likes due to the intervention of a higher portion between the drain and the centre of the road surface. The slope of the drain should be regulated by means of small *pucca* falls, if necessary, to prevent scouring of its bed. This work should also be taken up according to a well regulated programme as suggested for 1 and 2 above.

9. *Improving Sandy Portions.*—The next important item of improvement is to do something on the heavy sand through which the bullocks and buffaloes have to toil for hours before they can drag the heavily loaded carts through it. These portions are dreaded like those full of water, from the very start of the journey. It is necessary and possible to improve these at a comparatively low cost. Nine inches of clay from tanks or good earth from other portions of the road has been used with great advantage over such portions.

Usually 10 feet width with 2-foot edges on either side is sufficient but where there is heavy traffic 12 to 15 feet width may be adopted. This gives a very hard and good level surface like that of a metalled road. But it is very important to maintain it properly. The patches if any should be filled up annually with clay and the surface should be covered with two to three inches of sand before or immediately after the rains.

The clay should be renewed when it is broken up which usually takes from 5 to 10 years depending on the amount of traffic and the care in maintenance. The length of portions of each road to be taken up each year should be clearly set out in a clear cut programme like other items of improvement referred to above.

After dealing with the portions where there is heavy sand, it would be well to do soil classification of all the roads. It consists of taking a small sample of earth and washing it so as to dissolve all clay leaving only the sand behind from which the proportion of sand and clay present in the soil can be ascertained. It would be found useful to cover with clay all such portions of roads as contain over a fixed proportion of sand which can be easily determined by the bumpy condition of the road in each such mile where there is greater proportion of sand than required. A proportion

of 30 per cent of sand is often found to be the limit beyond which special treatment would be required in most cases.

10. *Surface Grading, Maintenance.*—The surface of the road should be graded so as to raise the centre, in a 20-foot width, one foot above usual flood-level and to level the sides on either side of the raised portion in a width of 10 to 15 feet graded to a slope of 1 in 40 with side drains or continued slope ending in a *dag bel* on the boundary of the road on either side. Where no raising is required, it would be best not to do anything more than grading the surface so as to give a slope of 1 in 40 from the centre of the road to the sides. The less the earth work done, the less bumpy the surface will be, for moisture and the grass near the original ground-level are of great help in preserving an unbroken surface.

The best, the speediest and the cheapest way to do the grading work is by means of the road grading machine. I was deputed to see the working of these machines in the Punjab and was fortunate enough to have the guidance of the President of this Congress, Mr. S. G. Stubbs, O.B.E., I.S.E., who was then the Secretary of the Provincial Board of Communications, in seeing closely the work being done by such machines in several districts in full detail, and in collecting all the statistics about the work done. According to my calculations there was a great saving to the tax-payer and very great relief to the motorist, who could drive at 25 to 30 miles an hour over the roads graded by the machine. My Board immediately purchased a road grader with a tractor, and I can testify, from the practical experience gained since, that roads repaired by manual labour can stand no comparison to those made by the machine whether in the quality of work done or in the cost, so far as the levelling and grading of road surface is concerned. The only difficulty in the use of such machines in Local Bodies is about the vehement opposition of contractors and their friends and the difficulty in securing the services of drivers and repairers in out-of-the-way places. Grading should be completed before or during the rains to allow the surface to set by rain water. No rolling will then be required. One cut can be given just after the rains. A small gang should be employed to lop off tree branches and to extract roots of trees on the track. In all seasons, except during the rains, usually the side *patris* on lower level will be found to be more convenient to drive on by the motorists leaving the central portion for the general traffic. If the work is required to be done in dry weather and the road is required immediately for use as in the case of some important functions, the surface can be watered and rolled after being graded by the machine.

Where no road grading machine is available the work of grading and levelling must be done through contractors or labour gangs, the contract being on the basis of so much per mile length of the road graded and not on the measurement of borrow pits. The raised portion can be better levelled by clearing the side-drain and utilizing the earth for levelling ruts and patches.

11. *Reservation of Track.*—The bullock-carts will take no time in spoiling the surface unless a track is reserved for light and fast traffic. This can be done by making a *daula* of, say, 1½ feet by 1 foot section separating the track reserved for such traffic from the track meant for general traffic. A ditch is not so useful as a *daula*. The local bodies concerned can frame bye-laws so that no vehicles except those coming

under the definition of "light and fast running traffic" shall use the reserved track. Without such reservation it is altogether impossible to maintain the surface, however well prepared, in a tolerable condition and the local bodies concerned are sure to receive thousands of abuses and criticisms daily from motorists, however much they might do in other directions to improve their roads.

Road gangs should be maintained to pass over these reserved tracks occasionally to fill up any patches, to look to drainage before and after rains and to guard against other traffic using the reserved track. The help of the Revenue Department and other district staff should also be sought to prevent unauthorized traffic from using the reserved track.

12. *Plantations.*—There should also be a regular programme for plantations along with other items of improvement mentioned above. The roadside *zamindars* and cultivators should be persuaded to plant their own trees on the roads along their fields on the condition that they would not cut these trees while they were still green. When they do not come forward, the plantation must be done by the Local Bodies themselves.

13. *Summary of Recommendations.*—To sum up, unmetalled roads should be divided into selected and unselected roads. Funds should be allotted on a milage basis for each. A programme of improvements should be drawn up for a period of years corresponding with the term of office of the local bodies concerned. The improvements should consist of (1) raising of depressed portions, (2) construction of bridges, culverts, and causeways, (3) improvement of drainge, (4) putting clay over sandy and soft portions, (5) grading of road surface, (6) reservation of a track for light traffic, and (7) plantations. The improvements should be maintained by the annual repairs of works constructed and by labour gangs working under properly qualified Engineering staff. From my eighteen years experience of the maintenance of earth roads, I have been convinced after trying all the different methods of work, that improvements Nos. 1, 2 and 4 can best be done through contractors, No. 5 by the machine and the rest departmentally through labour gangs and *malis.*

14. *Metalled Roads.*—I reserve my note on metalled roads under Local Bodies for some future occasion. At present I might say a few words only about their condition.

Metalled roads under Local Bodies mostly suffer from lack of funds and proper technical supervision. The minimum funds required for such roads should be calculated and provided in the budget which should not be passed until and unless this has been done. If sufficient funds are not available for proper maintenance the milage should be cut down and should not be allowed to be increased until funds are available for the maintenance in proper condition of the increased milage and the existing milage as well. Any grant made from provincial funds should be subject to the above conditions.

Much improvement can be effected, if what funds are available be utilized in the best way possible. In some districts it is cheaper to use stone ballast in preference to *kankar.* The change has brought about a saving of over Rs. 10,000 per annum in one district. Similar saving is possible in many other districts.

The technical advice of the Provincial Public Works Department should be made available to Local Bodies to decide such important matters of policy. Whatever allotment is available should be distributed proportionately and regularly according to the conditions of traffic for the whole of

the milage and the usual mistake of favouring one road only at the expense of others must be avoided. Much waste and inconvenience can be avoided by tarring or cementing all causeways and portions of roads in or near villages or towns. In fact, it may be found cheaper in the long run to maintain a tarred or concrete road in some places than a water bound macadam or *kankar* road. Specifications of tar, cement concrete and other roads should be made available to District Board engineers. Sufficient road gangs should be employed to maintain the surface and the *patris* in good condition. Breaches and obstructions should be promptly notified, guarded against and attended to by encouraging the subordinates who show better work in this direction. The experiments made by the Public Works Department engineers, and other technical bodies about the minimum width of road and minimum thickness of cement concrete, etc., can be adopted with advantage by Local Bodies for improving at least certain difficult portions of their roads, but this will only be possible when they get the necessary information about the same from some source.

Collection and consolidation at the proper time and of the proper quality should be insisted upon and the subordinates should get some encouragement or censure as a result of careful or careless work shown in this respect by each.

But these are matters of administration rather than of technique. What is required is to introduce technique in the method of maintenance of communications, both metalled and unmetalled, by Local Bodies. It will go a long way if the standard designs and specifications of the Public Works Department and such technical papers of the Indian Roads Congress as can be useful in the maintenance of the local communications are made available to District Board engineers as a matter of routine.

Discussions on Paper No. F.

Rai Sahib Fateh Chand (Author) : In introducing this paper I need not say anything about the importance of unmetalled roads. The President in his presidential address has already laid sufficient emphasis on this point.

I shall now read the criticisms on my paper forwarded to me by post by Captain G. F. Hall, Chief Engineer of Bihar. His written criticism runs as follows :

" The author of this interesting paper very rightly draws attention to the importance of local bodies' roads on the economic life of the people but when it comes to improving them, the effect on the floods not only of the district concerned but also of adjacent districts needs most careful consideration.

It happens as often as not that local bodies' roads run across the drainage line of the country; where they are at a low level, they cause little obstruction to flood flow which will find its way across without serious afflux, but once a local body starts raising its roads the consequences may be very serious indeed. The author refers to the construction of bridges, culverts and causeways but probably more due to lack of funds than want of foresight such provision is frequently totally inadequate to pass flood water without an objectionable afflux. The result is the impounding of water on the upstream side with consequent damage to crops and houses and in many cases the breaching of the road with a concentrated rush of water which causes even more serious damage to crops and property on the downstream side, to say nothing of far serious interruption of traffic, than would have occurred had the road been left at a low level and overtopped.

Even though the road may not breach for some years a silt bearing flood will build up the land above the obstruction and the alteration in the level of the country will result in serious disaster later.

Too much importance cannot be attached to the provision of adequate waterways. If funds prohibit them the road should on no account be raised.

The breaching of a local bodies' road may seriously affect a neighbouring district and even if adequate waterways are provided the position and dimensions of the bridges and causeways are of more than local importance for they may very easily adversely affect the waterways of an adjacent district with an approximately parallel road crossing the same drainage channels. Inter-district co-operation in the design and siting of waterways is far too often neglected. The raising or bridging of Government roads are considered by authority at headquarters and consequently their effect elsewhere can be considered and provided for ; but local bodies generally act independently and want of consideration for their neighbours may easily adversely effect the flooding of a large portion of the province.

Co-operation in this respect should be legislated for and no local body should be permitted to raise its roads without Government authority.

Given such authority the work can proceed on the lines Rai Sahib Fateh Chand advocates."

Mr. Ali Ahmed (Assam): The author of the paper Rai Sahib Fateh Chand has rightly laid stress on the importance of unmetalled roads in relation to future development of the country both politically and economically. The local bodies who have limited funds at their disposal have to maintain such roads and their problem is to make the most of

such funds and try to keep the roads passable meeting the demands made by modern traffic conditions.

The Rai Sahib has very rightly laid stress on the great advantage which results from the use of road grading machinery. I fully agree with him in this, and our experience in Assam shows that quite apart from such advantages, as speed of operation and a higher standard of grading and dressing the road surface, there is actually a good deal of saving in the maintenance estimate by the use of machinery, that is to say tractors, road-graders, planers, and rollers, etc.

We in Assam have a very large mileage of unmetalled roads as compared to metalled roads. All the roads maintained by Local Boards, with the exception of few, are unmetalled and the ratio of those maintained by the Public Works Department is 1 metalled to 3 unmetalled. Owing to very heavy rainfall in the Province the unmetalled roads used to become practically impassable during the rainy season but a great deal of improvement was brought about no sooner than the use of road maintenance machinery was introduced some eight years ago. It was found that with the exception of periods during the rainy season, when owing to heavy and continuous rain nothing could be done, the road could be kept open to motor and other traffic by grading and dressing the surface during fine spells of weather by use of caterpillar tractors, grading and planing machines and a 4-ton triple roller. Soon afterwards the use of gravel on the road surface was introduced and by giving a very light initial coat of about 1½ inches thickness the road was improved to such a great extent that even during the heaviest rains it was kept in good condition. As a result of the improvement commercial motor traffic has sprung up and buses and lorries now freely use the improved earth roads throughout the year.

This is as it should be, but the important point about it is that there was no increase in the average maintenance cost of the roads per mile. The repairs to *kutcha* surface with earth and with manual labour, have actually been costing more than the initial coats of gravel on the surface and its subsequent repairs with the same material. Figures that I will cite go to prove this.

In 1928-29 the mileage of Public Works Department roads was 409·81 metalled and 1,362·01 unmetalled the proportion of metalled roads to unmetalled being ·30, and the total maintenance cost was Rs. 17,87,796 which works out at Rs. 1,009 per mile.

In 1936-37 the figures respectively for metalled and unmetalled mileage were 626·7 and 1,878·4 giving a proportion of ·33, and the total maintenance cost is Rs. 21,97,810, giving the maintenance cost per mile at Rs. 877 only. This shows that although the proportion of metalled roads to unmetalled increased by ·03, the average maintenance cost of the roads has decreased by Rs. 132 per mile or by 13 per cent.

In obtaining these results gravelling as well as the use of graders has played the most prominent part. We have at present a fleet of twenty-one tractors, all of them caterpillar make, with their complement of graders, planers and triple rollers, to maintain 1,878 miles of unmetalled roads. The cost of the tractors exclusive of that of graders, planers and rollers is about Rs. 1½ lakhs. All these machines had been purchased from the road maintenance grants and their cost was from time to time included in the annual maintenance cost of the roads.

The main problem about the use and upkeep of these machines is proper arrangement for their repairs and overhaul. We have suitable

arrangement for this, and our Mechanical Sub-division is able to carry out all necessary repairs in our own workshop. The establishment cost of the Sub-division is only Rs. 11,000 per annum which includes one Mechanical Engineer on Rs. 725 and one Foreman on Rs. 180 per mensem and the necessary clerical establishment. The cost of spare parts and labour in repairs is of course separate, and is debited to the road maintenance estimates.

The average cost of one operation with the machinery over a mile length varies from Rs. 6 to Rs. 12, the cost being dependent upon the number of times a machine has to go over a particular mile, its distance from the machines depot and other factors such as the nature of the soil, the traffic and the rainfall.

From these remarks, it would be clear that if the local bodies who have a large mileage of unmetalled roads to maintain, introduce the use of road maintenance machinery they will be able greatly to improve their roads without the need of additional grants.

The difficulty with the local bodies, however, is that they are small units independent in their administration. and the manner in which a well-organized and large department of Government can set about to solve its problems, it is impracticable in case of a local body to do so with its scanty resources and limited scope for work.

I am aware of the problems which local bodies have to solve and difficulties they have to face. Lack of funds. lack of programme, lack of continuity in the policy of the board. very often slack supervision on the part of the chairmen, all these contribute towards neglect of the roads. deterioration of bridges in many cases for want of repairs, wearing out of the entire metalled thickness of roads, no funds being given for renewal costs, etc., such things are only too common. In such circumstances, technical advice can be of little avail, and the engineers or surveyors entertained by local bodies can have little enthusiasm in their work. It is hoped. however, that the drive for rural uplift and better communications to villages, and the enthusiasm of Ministers in self-governing provinces of British India who hold the Local Self-Government portfolios, will bring about a change for the better and devise some means by which the activities of different local bodies in a province can be co-ordinated, programmes for improvement chalked out, and help rendered to such local bodies whose resources are too limited to enable them to stand on their own legs. I mention this with the specific object that without this the introduction of the use of road machinery on a desirable scale will be found to be difficult, and even when the initial cost of their purchase can be found, the knotty problem of their repairs and overhaul at reasonable cost and in good time. as well as that of keeping a stock of spare parts, cannot be solved by each local body for itself.

In Assam we have endeavoured to solve this problem for the local boards, by encouraging the boards to borrow the Public Works Department machines on payment of a daily hire. Such a solution is, however, impracticable in a province like the United Provinces. where, I understand, the Public Works Department have no unmetalled roads on their books and consequently, have no road machinery to lend.

The author of the paper has advocated the use of clay 9 inches thick on sandy portions. If clay is not available within a reasonable lead, the cost of this would be tremendous. Our experience in Assam has been that gravelling even when gravel is brought from a distance by train is cheaper than coats of clay or sand used for stabilization of soil. The

minimum thickness of gravel laid is 1½ inches, the cost varying between Rs. 15 to Rs. 25 per 100 cubic feet delivered at site. Where gravel is not available, broken stone of sufficient hardness can be used.

Gravel has the further advantage of keeping off the main track bullock-cart traffic, as the bullocks seldom prefer a gravelled surface to an earth one.

I hope the points dealt with by me will be of interest to those who are endeavouring to solve the problem of maintenance of unmetalled roads.

Rao Sahib, M.A. Rangaswami (Bihar): I should congratulate the author on his paper which presents in a lucid manner the problem of road maintenance in local bodies. Everybody agrees with him that the unmetalled roads form the bulk of road system in rural areas and with the progress of education and raising of standard of living and other improvements both economical and social, there is a consistent demand for improvement of rural communications, particularly of unmetalled roads. With the limited funds available for road maintenance and the demand for greater improvement in road surface, the engineers, particularly the District Engineers who have to do lot of maintenance of District Board roads, have to face a very difficult situation. In North Bihar, especially of Darbhanga District, the maintenance allowance for unmetalled roads is only an average of Rs. 35 per mile.

It is very essential to have roads classified—I believe they have been classified in many provinces—and in Bihar, the unmetalled roads are classified as class II(*a*) and II(*b*) and III and IV class roads, and minor village roads are classed as Local Board "Daggars."

Class II (*a*) represents roads bridged and drained throughout and II (*b*) partially bridged and drained; class III is unbridged but moorum roads and class IV banked roads are partially bridged and fair weather roads only.

In Darbhanga District the more important roads get Rs. 50 per mile and the rest Rs. 25 to Rs. 30 per mile, for maintenance. This includes the cost of maintenance of cart tracks. For bridges and culverts, annual repairs a sum equal to 30 per cent of the allotment under "Communications" is set apart in addition to the surface repair amounts.

The one chief difficulty is that the allotment under Civil Works "Communications" gets reduced every year or varies and is on the decline and the mileage of unmetalled class III and IV roads increases rapidly, a tendency which is ruinous but which cannot be curbed. This indiscriminate growth of IV class roads tells on the maintenance of other class roads, as allotment for such roads being already inadequate, gets naturally reduced to meet the cost of maintenance, though of a poor kind, of the IV class roads which get the increase. Roads, therefore, deteriorate for inadequacy of allotment which is already poor and becomes poorer year after year.

The essential technique of maintenance of roads, as described in the paper under discussion, is known to every road engineer, but the main difficulty, rather I should say, the problem before the engineer is how to get funds for the normal upkeep of roads and how to stop the tendency of diversion of funds for other purposes, such as education, etc., from the funds normally used to be allotted to communications. Whenever any road is bad or the standard of maintenance is deteriorated, the blame goes to the engineer and he is damned but those responsible for the indiscriminate growth of roads and curtailment of funds get scot-free.

The next point touched is about the fixation of a certain minimum percentage to be spent on communications and although this is desirable the enforcement of such a practice will present vast difficulties, it being mainly an administrative concern.

Especially in flood affected areas, as in the case of North Bihar, any raising of roads should be done with due deference to its flood effects on neighbouring districts as well. I have actual experience of a District Engineer raising a road in his district, of course, providing waterways as found necessary, but it spelt disaster in the neighbouring district, which had not been appraised of such raising, with the result that the roads and bridges in the neighbouring district were seriously threatened. What I wish to emphasise is that any raising of roads should be done considering not only the interests of the particular locality but also its effects on neighbouring districts and the question will have to be tackled as a larger problem affecting the different districts.

In banked roads as in the case of Bihar where labour is cheap, the maintenance of roads by gang system appears to be preferable. I have introduced the gang system in my district and the surface so maintained is appreciably superior. It provides employment to labourers and from this point of view, I should oppose the system of grading with a mechanical grader.

We have in Darbhanga District as practically all over North Bihar, the slow-moving traffic as bullock-carts segregated from the fast-moving traffic, by providing what are called *licks*. Special road patrols are engaged to see that carts run on *licks* only and infringers are prosecuted under the District Board bye-laws. Although this has considerably kept the slow-moving traffic on *cart licks*, still the system is very defective and requires considerable improvement as in most cases it becomes a source of nuisance and extortion to the village cartmen.

Mr. Raj Mohan Nath (Assam) : Rai Sahib Fateh Chand has in his interesting paper justly complained of poor provision of funds for roads under local bodies. This is the cry everywhere. I know of a local board which has got about 450 miles of roads, mostly unmetalled under the management of one surveyor and two sub-surveyors with an annual grant of Rs. 29,000 only for general maintenance, including repairs to bridges and resthouses, etc. The position is gradually becoming more serious on account of many miles of roads being constructed now out of rural uplift funds of the Central Government and then handed over to the local boards for maintenance. The Rai Sahib mentions on page 2 (*f*), para 5. that the allotment for unmetalled roads has been the first to be curtailed when the funds are required for any new expenditure. This state of affairs can be stopped if I am allowed to say so by starting a Society for Prevention of Cruelty to Roads.

With such meagre funds, provision of reserved side tracks for special traffic as suggested by the Rai Sahib, seems to be a luxury beyond the means of the Public Works Department of many provinces, not to speak of local bodies. Moreover, to seek the help of the Revenue Department to enforce bye-laws for the use of the reserved tracks only by "light and fast running" traffic even in the country area appears to be a very difficult problem, not of great practical value.

The idea of putting a 9-inch layer of clay over sandy portions of roads is no doubt good, but there may be places where the cost of carriage of

about 48,000 cubic feet of clay may go very high. The Rai Sahib has not given us any idea of cost.

The idea of almost every local board is to lay out the minimum of money for road repairs but get the maximum of service from the road surface. Mr. Ali Ahmed, Superintending Engineer, has told you just now what we have been doing in Assam to improve the *katcha* roads by a simple method, and make the road surface passable to all sorts of traffic throughout the whole year. This is by gravelling a 10 feet width of the road with a uniform 1½-inch coat of shingle, ¼-inch to 1¼-inch gauge. Where the surface is very sandy, the gauge may be increased to ¾-inch to 1½ inches. Natural river-borne shingle, quartzite or sandstone is the best; but in places where these are not available, stone broken to the above gauge in a granulator or by hand is the second best; the hand-broken stuff makes the road surface a bit rough.

It may sound paradoxical to many that a *katcha* road which during the rainy season becomes muddy, and during the dry season sandy can be dealt with by a poor coat of gravel of 1½-inches thickness to any appreciable advantage; but shingle laid on the road surface after properly cambering it (2 inches in 10 feet width is enough) at the right moment gives excellent results. What is aimed at is not a thick solid bed but an impervious solid crust. In a sandy road, after a shower of rain, when the sand has just been killed, before the monsoon really breaks, the shingle is to be spread up at once. In a clay road shingle should be laid about the same time, but before the sub-soil becomes too soft. Too soft or too dry surface is not good at all as the shingle will simply be lost. Shingle laid on the proper surface at the right moment combines with sand, clay and dust, and under the thrust of traffic forms a kind of impervious carpet that keeps the road surface in tact.

I had the opportunity of dealing with a few hundred miles of roads which during the rainy season used to become a deep bed of sticky mud, and in the dry season a thick cushion of sand—both terrors to traffic; but a thin coat of 6,600 cubic feet of shingle laid generally before the monsoon broke has now made these roads pleasant drives throughout the whole year. Of course, the initial coat followed by annual supply of shingle for patch repairs or renewal coat of 500 cubic feet to 3,000 cubic feet per mile as occasion demanded were necessary. The method is now followed all over the Province of Assam.

Ordinarily, shingle laid on the road is rolled by traffic, the labour gang on the road scraping back with garden rakes the shingle that has run out to the sides; but a light rolling with a tripple roller—as designed by Mr. A. A. Barnard, I.S.E., Executive Engineer, Assam, and manufactured by Messrs. Burn & Co. Ltd., Howrah, pulled by a tractor—has been found to be quite good. Such roads have been found to carry an average weight of 30 tons per yard width per 24 hours near a tea garden area and the rainfall varies from 78 to 105 inches a year.

The cost per mile is calculated at Rs. 5 per 100 cubic feet for collection at the quarry, Rs. 1-4 per 100 cubic feet per mile for carriage, and Rs. 0-12 per 100 cubic feet for spreading; the average cost per mile being Rs. 500 to Rs. 1,600 according as the distance of the quarry from the road is one mile to 10 miles respectively; and the average life of such a coat is at least four years, and the average maintenance cost is Rs. 552 per mile, including patch repair and renewal coat of gravel as occasion demands including grading and planing the road with a tractor from time to time to bring the road surface to proper camber.

Mr. U. J. Bhatt (Bhavnagar State) : I just rise to draw attention to paragraph nine of the Paper. The author has used the idea that sand could be improved by adding clay. In Assam clay could be improved by adding gravel. In our State we have a programme for hundreds of miles of unmetalled roads. The Honourable Raja Sham Raj Rajwant Bahadur in his inaugural address drew pointed attention to the need for improving unmetalled roads. My suggestion is that we should work out data relating to the proportion of clay, sand. etc., for use on unmetalled roads. It is particularly gratifying to note that the Government of India have appointed a Soil Physicist to help the Road Engineer. By combining a knowledge of the science of soil mechanics and then devising methods and correlating them we can give engineers a reliable guide to improve the soil for unmetalled roads. I myself carried out some laboratory and field experiments and shall be glad to present the results of these experiments at the next Congress. It is absolutely essential that we should know much more about soil characteristics than we do at present if we are really to improve the condition of unmetalled roads in this country.

Mr. Syed Arifuddin (Hyderabad-Deccan) : Rai Sahib has brought to notice in this paper the importance of paying attention to less important unmetalled roads and has shown how they can be improved and has explained the important points which require special attention in the improvement of these roads.

There are a few points in connection with this paper I should like to speak on.

With regard to the size of the borrow pits Rai Sahib recommends that these should be of uniform size and shape. I find in practice that unless the quantity required is very small, it is not practicable to have borrow pits of uniform size all along the road as the quantity required varies from place to place. I prefer to insist on having a uniform width and depth but altering the length of the borrow pits, which runs at right angles to the road. according to the quantity required.

In connection with the width of the road on culverts. he reccommends 14 to 18 feet for selected and 10 to 12 feet for unselected roads. In my opinion the minimum width should be that which will allow cars to pass at slow speed without the necessity of any of them coming to a dead stop. This can be fulfilled by a width of at least 14 feet I would, therefore, recommend a minimum width of 14 feet between the parapets for less important roads and a width of 20 feet for more important roads which will allow cars to cross each other without reducing speed.

With regard to road widths he recommends 15 feet for unimportant and 20 feet for more important roads. 15 feet. in my opinion, is much too small for any future road. No road, however unimportant, should be less than 21 feet and more important roads less than 30 feet in formation. In the past, engineers used to consider a bank as very important. These ideas are changing fast. Before the advent of automobiles slow traffic was not inconvenienced by numerous changes of gradients in short bits. The fast traffic has altered the design completely and we do not want so many changes of gradient. If we adopt the old policy of taking the road in banking generally we shall have to allow numerous gradients of short lengths to suit the natural ground or will have to go in for expensive banking if we want to have long gradients. This trouble can much more easily be remedied by taking the road in cutting and banking freely so as to reduce the cost of formation of the road to a minimum consistent

with the importance of the road. I, therefore, agree with Rai Sahib that unnecessary raising should be avoided. There is one point which I should like to make clear in this connection. Some engineers are under the impression that if a road is taken in cutting or on natural ground the drainage of the sub-soil becomes very defective. In my opinion, the solution of this trouble lies in having effective side drains.

In the opinion of the author of the paper soil consisting of more than 30 per cent of the sand is not suitable, or in other words the less the sand the better; this may be true for the sandy soils met with in the United Provinces but my experience of the soils obtained from the disintegration of rock, particularly granite, and gneiss is quite different. I find that the greater the grit in the soil the better it is for banking. I have made a very effective road on a bank consisting of black clay with rocky moorum which contained less than 10 per cent clay. This is particularly applicable to all kinds of soils which are not of sedimentary formation. Even the disintegrated trap makes a good bank if it contains small percentage of clay.

Rai Sahib has touched on a few points of the maintenance of metalled roads as well as the question of budget allotment for district roads reserving his important views for some further occasion. I should have reserved what I wish to say now until I have the pleasure of seeing his paper, but thinking that my views may create new thought of some utility I have taken the liberty of mentioning them here. The reconstruction of the metal surface is necessitated partly by the wearing away of the metal and partly by the surface becoming uneven due to impact of load. etc. Reconstruction is generally done at an interval of five or six years but the surface usually gets disturbed in three or four years. To maintain the surface in good condition for five or six years is generally a difficult task. As an alternative to heavy patch work I would prefer to rake up the whole metal after three years by sacrificer, regrade and consolidate it with an addition of very little new metal just enough to fill up the hollows and to give it the necessary camber, if required. This operation will keep the road surface in good condition for another three years at the end of which it can be reconstructed with 3 inches of new metal. I have conducted this experiment on a small portion of a road and found it satisfactory. I find that this is the best and very convenient way of keeping the road surface in good condition for six years. It might be possible to do this operation, adding a little metal. once in four years, and the reconstruction once in seven years, to reduce the cost. However, this idea may be tried on a large scale and if proved successful, might be adopted.

With regard to the allotment of maintenance grant the general tendency is to fix one rate per mile for all the roads of the same type. What I consider the best policy is to determine the cost of reconstruction mile by mile, taking the lead of material into consideration. fix a sum which will be sufficient for the reconstruction of the whole road during the period fixed for it. The Engineering Department should be able to draw annually as much as is required for the completion of the programme of reconstruction of that year. This system will alter the grant of a road per mile for different roads which will be more in keeping with the actual fact.

Once a grant is fixed for the whole road for a given period, it is immaterial financially how this is distributed over the period. This method is applicable to moorum as well as metal roads equally and might result in better up-keep of the roads.

Mr. S. G. Stubbs (President) : In the Punjab we have hundreds of miles of such roads. We do not use fresh metal for repairs but merely repaint.

Mr. A. Nageswara Ayyar (Madras) : Almost all unmetalled roads in the Madras Presidency are in charge of the local bodies except for a few miles of roads in the *ghat* sections.

The proportion of metalled roads to unmetalled roads is very high. About 80 per cent of our roads are metalled.

Mr. S. G. Stubbs (President) : Presumably this is because the cost of metal is very low in the Madras Presidency, I suppose.

Mr. A. Nageswara Ayyar (Madras) : No. It is because the people will not have unmetalled roads. I have heard one of the speakers say that in Assam the cost of road works out at about Rs. 1,000 per mile. In Madras the average maintenance cost of metalled roads is only about Rs. 200 per mile. The thickness of the metal layer rarely exceeds 4 or 5 inches. In areas of black cotton soil a layer of about 4 to 5 inches of gravel is laid directly on the black cotton soil and lasts for about two to three years with a fair surface. If on top of this a layer of about 4 inches of metal is spread the road lasts for many years longer. At the present time there are about 25,000 miles of metalled roads in the Madras Presidency. The clamour for more roads is so great that we are unable to find funds for them.

In our experience we find that earthen roads should be raised some height above the side drains.

Mr. S. G. Stubbs (President) : If the side drains are kept open then there would be no need to raise the road level.

Mr. A. Nageswara Ayyar (Madras) : Yes. The author of the paper has advised the laying of about 9 inches of clay over sandy subsoil. I find that about three to four inches of gravel is the best. If clay is used at all it should be only a few inches thick and not as much as 9 inches in thickness. In the East Godavari District I have found that 4 inches of gravel over a sandy base is very successful.

Regarding the use of road graders the gentleman from Assam has said that they have been used very successfully in Assam. But our experience in Madras is quite different. We find that graders cannot be used very usefully. On the whole it is cheaper to use manual labour. The scope for the use of graders in an economical manner is quite limited, perhaps because we have no large mileages of unmetalled roads.

Mr. A. Lakshminarayana Rao (Masulipatam) : I did not want to speak when the paper was presented. But a number of questions have been raised during the discussion on points which are not referred to in the paper and I, therefore, feel compelled to say a few words. There is a strange suggestion on page 3 of the paper. I can understand that bridges cost proportionately less when the width of roadway is reduced. But it is not so in the case of causeways. The conditions of traffic today are not what they were a decade ago, and the conditions of traffic ten years hence will not be what they are today! Suppose there is a sandy stretch over which a causeway has to be built. We must look ahead when designing such a causeway. We have to remember that it is very unwise to consider conditions obtaining at the time the design is made. A 12-foot causeway may suit conditions of traffic at the time of design but may be completely unfit for conditions ten years

hence. The difference in cost between an 18-foot causeway and a 12-foot causeway is not very much. It is, therefore, undesirable to construct narrow causeways which will not allow two lines of traffic to pass.

Regarding earthen roads, the author seems to think that because we have a large mileage of earthen roads now it will be so always! (*laughter*). India is advancing so rapidly that in twenty years earthen roads may be discarded and converted to metalled roads. We build our roads not merely as earthen roads but as roads which can in course of time become metalled roads, asphalted roads and concrete roads in stages! (*laughter*). On all sides we are hearing of the increasing importance attached to the villager and villages. The gentleman whom we now call as the villager is becoming greater in importance every day and will perhaps be the Honourable Minister of tomorrow and direct policies of Government. So, to look upon earthen roads as though they are going to be so for all time, is not quite the wise thing to do! It is common experience that roads do not last long unless they are raised at least about 2 feet from the surrounding level. But conditions differ in different places and it is not possible to lay down cut and dry rules applicable to all conditions. Each case will have to be decided on local conditions. One gentleman says that sand should be spread over clay, another says that clay should be spread over sand, another says that gravel should be spread over sand or clay, one says that the layers should be 9 inches thick and another says that they should not be more than 4 inches in thickness . . . (*laughter*). This only shows that local conditions are the deciding factor. There is therefore absolutely no meaning in trying to evolve a common formula applicable to all places. There are some places where the loose surface, presented by sandy soil is a great problem. On the other hand there are places where it is quite a difficult thing to get sand. One collector in charge of such a district humorously remarked, that in that district it was easier to get gold than sand or stone.

With reference to the use of road graders, I may say that I was in charge of one of these graders for some time. I was an enthusiast about the grader. The success or failure of a grader depends very much on the distribution of the rainfall in a particular area. If there is a rainfall of about 30 inches within three months then the grader can be used successfully. But if the same rainfall is spread over six months then the grader may not be of great use. Thus, success of the grader also depends on local conditions.

Captain R. C. Graham. (N. W. F. P.): We have so far heard a number of speeches on this paper, but, in my opinion, we rather seem to have missed the boat! The Paper is on "Roads under local bodies and *how to maintain them.*" We all perhaps know how to keep a road in condition. But we also know that to maintain roads satisfactorily the first essential is money. I suggest that our Council should induce the Government of India to bring pressure to bear on the local bodies to set aside a fixed percentage of their income for expenditure on roads. The revenue officers in the districts know the exact income of the local bodies and what their income should be. It should not be difficult for the Government of India to evolve a system whereby a fixed percentage of the income of local bodies is automatically earmarked for expenditure on roads. The percentage may be fixed according to the resources of the local bodies concerned.

Mr. G. B. Vaswani (Sind): I am of opinion that the rural people have become road-minded. They want metalled roads. They do not

want bullock-carts and earthen roads to be provided for them. Improvements to local roads can only be done by taking a bold policy and applying for a loan. Karachi Municipal Corporation adopted this procedure and had all its roads covered with asphalt by raising a loan of Rs. 3 lakhs. As a result the roads have definitely improved and in the end it has proved cheaper to the Corporation. They would have spent more on maintenance, had they continued their old road policy and spent their usual allotment on their maintenance. Therefore it is cheaper in the end to adopt a bold initial policy.

Mr. E. A. Nadir Shah (Bombay): Only two classes have been mentioned (1) Unmetalled Roads and (2) Metalled Roads. Surely time has now come when the local bodies should have the third and more important classification, viz., road surfaced with asphalt or concrete, as by increase in mileage of this classification, there is bound to be low maintenance cost and better type of surface suitable for modern traffic will be provided.

It is a great pity to find that Road Maintenance Funds have been reduced as much as by 60 per cent instead of a substantial increase and the road engineers either in a body or individually should exert most to get more funds or improve road conditions particularly when income from road users is far more than what is spent on roads.

On page 2, the author says 20-feet width should usually suffice. May I suggest that to provide enough room for two lanes of traffic according to modern practice, it should be increased to 22 feet, i.e., 11 feet for each lane. For one lane of traffic 15 would do as, when overtaking or passing, one of the vehicles will have to travel on the berm for a short time. I may here mention that the Ministry of Transport suggest a minimum of 20 feet but looking to our conditions in this country 22 feet, I think, should be the minimum for two lanes.

I may refer the author and those interested in road building with tractors and graders to a very interesting and instructive pamphlet issued by the Indian Roads and Transport Development Association on this subject (Pamphlet No. 11) wherein reports from various parts of India such as Indore, Baroda, Punjab, Assam, Southern India, etc , regarding cost of road building with tractors and graders have been given.

On page 3, the author says that 14 feet to 18 feet width for selected and 10 feet to 12 feet for unselected roads would do. In old days when the cost of bridge construction was very high, this practice of narrowing a roadway at and on the bridge was followed ; but in modern days when the width of the bridge can be increased for a comparatively small amount, I think the width of the road on a bridge should be same as at other places.

I entirely agree with the suggestion made by the author in paragraph 11 on page 4 of the paper regarding segregation of traffic.

Mr. L. B. Gilbert (Chairman): Before calling upon Rai Sahib Fateh Chand to reply, I would say something about the paper myself. I wish to refer to a suggestion made by some of the speakers that a resolution should be passed requesting the Government of India to have pressure brought to bear upon the local bodies to set apart a percentage of their income for expenditure on roads. It must be remembered that Provincial Autonomy has been introduced. Any suggestion from the Government of India that pressure should be brought to bear on local bodies would be resented and do more harm than good.

Rai Sahib Fateh Chand (Author): I find my task rather a difficult one because several members have offered their criticisms and

raised many new points while the time at my disposal is very short. Most of the speakers have laid stress on the fact that most of the local bodies suffer from lack of funds. I wish the local bodies all over India had at their disposal the mighty resources of the Hyderabad State. In the present state of finances of the local bodies no progress is possible. Various suggestions have been put forward to improve matters. One such is to bring pressure on the Government of India. As has been pointed out by Mr. Gilbert, that may not be possible. Another suggestion has been to start a society for the prevention of cruelty to roads. In fact, I think, the Indian Roads Congress itself should act as such a Society for the prevention of cruelty to roads.

Our duty as engineers is to prevent these roads from becoming death-traps. In many places, for many years, many miles of roads have not been attended to at all. It appears to me that something can be done by the Indian Roads Congress at least in suggesting to the various provinces that they should have a certain percentage of their income earmarked for the maintenance of roads. The difficulty with the local bodies is that they do not know how much they should spend every year. If a census is taken, it will be found that the value of lives lost is much greater than the amount saved by not repairing the roads in time, and the money spent on the reconstruction of these roads and their maintenance is much more than what it would be if a regular programme was adopted in regard to these roads.

Another point is about the method of maintenance. Several members referred to the raising of the roads above the surface level. When I went on horse back I found that these raised roads were quite alright. But when I went in a motor car, I found that the worst portions of the road were those which had been raised. When for the first time I went to the Punjab, where Mr. Stubbs is the Chief Engineer, he said that the road should never be raised and the original surface was the best for motor traffic. It looked very strange, but when I came back to my district I found that I had been wrong. After an experience of eighteen years in road making, my opinion is that the raising of roads should not be carried on beyond certain limits in places where there is no danger of water-logging. The surface should be raised well above the flood water level and properly drained.

There has been a lot of discussion about the width of the road. Some members have observed that 20 feet is not sufficient. I say it is a necessary evil that you have to adopt. It is simply to make the roads passable during floods. My experience is that the raising should not be more than 20 feet in width. There are several roads in the interior parts of the districts over which you cannot pass through. Even bullock-carts cannot pass through. So long as we have got such roads, it is necessary for us first to make these roads passable. The width can be increased afterwards. On principle also, I do not recommend the increasing of the width or the height of abutments beyond a foot above the flood water level.

I will next come to the question of the improvement of the surface. One of the most successful surfaces is clay. Clay is available everywhere. Villagers everywhere take earth for the construction of their houses. What is required to maintain clay surface is to just put in 2 to 3 inches of sand over it and after a few years again put 3 to 6 inches of clay to maintain the original thickness of 9 inches. I quite agree that where clay is not available, gravel can be used with advantage. But the cost will be

very great. Clay costs Rs. 1 per 100 cubic feet only against Rs. 12 per cent cubic feet for gravel. We have tried "Kankar" tracks, but these have proved a failure.

The main criticism offered about the graders is that they cost enormously initially. The main consideration should be the maintenance of roads at the cheapest cost, but if the cost can be reduced no other consideration should stand in the way.

Another point is about the staff and the co-ordination of activities. There should be some provision for minimum staff. Many of the districts have not sufficient or efficient staff. It should be provided for according to standards to be laid down by the Indian Roads Congress.

One of the speakers suggested that it was difficult to make borrow pits of a uniform section as more earth might be required in one place than in another. For this purpose the dimensions of the borrow pits should be calculated according to the actual requirements of earthwork at each point, but all the borrow pits at the point should still be made of a uniform size and shape determined for each place. I lay special emphasis on this point because I have come across not hundreds but thousands of cases in which the contractors have tried to take advantage of some existing depressions or old borrow pits in such a way as to leave the *tattis* and *malams* at some of the highest points only or in place of the old ones where they might not have been completely removed on previous occasions.

I have suggested that causeways should be provided if sufficent funds are not available to construct bridges of sufficient waterways. It is very important that the point of the adjoining country not becoming flooded and damaged, should always be borne in mind. As Captain Hall has suggested, some of the local bodies may not care for the safety of the adjoining districts. For this it should be possible to take action under the law, which should allow payment of damages equal in amount to the loss actually caused.

For light traffic it is impossible to prevent formation of patches and ruts so long as the bullock-cart is allowed to go over it unrestricted. One side and not necessarily the centre of the road can and should be reserved for light and fast traffic. It is an absolute necessity, not a luxury, in the case of important unmetalled roads at least. This is possible, without any appreciable expenditure, through the existing Public Works Department staff, with the co-operation of the Revenue and the Police staff, who are equally interested in the matter ; but it is necessary to frame suitable bye-laws before resorting to reservation or inviting the assistance of the Revenue or the Police staff.

The first duty of the local body is to make its roads passable. It is for this reason that I have suggested the minimum width consistent with the safety and convenience of the traffic that passes over it. I have noticed bridges on first class metalled roads of the minimum width suggested by me for unimportant earth roads over which a car or a motor bus may not be required to pass more than a dozen times during the course of twelve months. It has been suggested that times are fast changing and the width should, therefore, be such as would be suitable for the motor traffic of the future. As time advances there will be greater and greater demand for additional mileage of *katcha* roads. All the cart tracks of today will eventually be turned into earth roads and the first demand of the traffic would be to make these roads passable at all times of the year. For this reason it is all the more necessary that the width of the embankment, bridges and causeways should be the minimum

required for the traffic that usually uses or is likely to use it in the near future. In the specifications for bridges issued by the Indian Roads Congress the width of 10 feet for one line of traffic has been suggested. My suggestions are based on this recommendation. In the case of very important unmetalled roads where a double line of traffic might be expected, the width of the bridges can be increased to 20 feet as suggested by me already for embankment. I recommend the same width for causeways as for bridges, because the extra width is unnecessary and the two long walls of the causeway can later on be utilized as the curtain and wing walls of the bridge.

Some of the speakers have suggested a thin coat of metal in place of clay or gravel. Metal laid on sand or weak foundations does not stand and when broken up makes the surface most inconvenient to travel on. Coal dust with or without molasses can be used with better results and at comparatively lower cost, where clay or gravel is not available.

Standard Specifications and co-ordination of activities are most essential as some of the speakers have suggested.

In the end, I thank the various speakers for the very keen interest they have displayed in this paper and for the valuable suggestions made by them in connection therewith. I particularly thank Mr. Ali Ahmed, Superintending Engineer, Assam Public Works Department, for his most valuable contribution on the subject.

Paper H.

Mr. L. B. Gilbert (Chairman): I would call upon Mr. Ian A. T. Shannon to introduce his Paper on "An Aspect of Traffic Statistics."

The following paper was then taken as read:—

PAPER No. (H)

AN ASPECT OF TRAFFIC STATISTICS.

By

IAN. A. T. SHANNON

C/o Burmah-Shell Oil Storage & Distributing Co. of India Ltd., Madras.

1. In this short paper the writer has not attempted to propound any theories or rules for the analysis of traffic statistics but it is his object to put forward for consideration the suggestion that the Test Track at Alipore should be utilized in an endeavour to reduce to some common ground the correlation of traffic statics in so far as they affect road surfacing, a question which, it will be admitted, is of much interest and importance to all concerned in the design of road surfacing.

2. The importance to the road engineer of statistically examining the traffic which the roads under his charge have to bear, is now generally recognised, and three very detailed and instructive papers on this subject were presented before the second Indian Road Congress held at Bangalore in January, 1936, viz. Papers Nos. 14, 15 and 16, by Mr. R. L. Sondhi, Messrs. H. P. Sinha and M. M. Abbasi, and Lt.-Col. W. DeH. Haig. Since then there has been, at any rate, in the Madras Presidency, a much increased recourse to traffic statistics in connection with road surfacing proposals.

3. There are a number of directions along which traffic statistics can serve as a valuable guide. Data regarding the number and types of vehicles using a particular road will assist in deciding upon improvements such as increasing carriageway widths, creating dual carriageways, by-passing towns, etc., and in this direction the application of statistics is a fairly straightforward matter. The other major application of traffic statistics, i.e., their use to determine what type of construction is most suitable, in the light both of eventual economy and current financial conditions, is a much more complicated and uncertain matter. That this is so was made clear in the three papers read at Bangalore, already referred to, and in the discussion to which they gave rise.

4. Methods of taking traffic statistics may vary in different parts of India, but their essence is the same, i.e., to ascertain the number and weight of vehicles using the road under observation. In Mr. Sondhi's paper a description was given of a very detailed and complete census taken around Delhi. This census was not taken solely to provide information in connection with road surfacing and had this been the case, possibly it would have been thought sufficient to take counts of 'buses and lorries and steel-tyred traffic only, for it is generally agreed that the damage caused by the other vehicles, i.e., light pneumatic-tyred and wooden wheeled types are at worst capable of solution by comparatively inexpensive methods.

5. On this basis we are left with the evil of the action of 'bus and lorry traffic combining with the action of steel-tyred traffic in various volumes and proportions. No method seems to have been yet evolved for deciding with any degree of accuracy what types of surface are required for roads carrying different volumes and proportions of these two main types.

6. At one end of the scale a very small volume of steel-tyred traffic with a large volume of 'buses and lorries can safely be provided for by surface dressing the ordinary waterbound macadam construction. At the other end of the scale a similar volume of 'buses and lorries but with a greatly increased volume of steel-tyred traffic will necessitate either high initial expenditure on a heavy duty surface or frequently recurring expenditure on maintenance if the road is to be kept in good condition. Between these limits, which might, purely for the purpose of illustration, be taken at 500 total tons of 'bus and lorry traffic and 100 tons of steel tyred traffic per day at the low limit, and over 500 tons of 'bus and lorry traffic with over 1000 tons of steel tyred traffic at the high limit, there lies a range of volumes and combinations that it is at present almost impossible to cater for with any considerable degree of accuracy as to probable life.

7. Possibly the most satisfactory way available at present of dealing with traffic census figures, in so far as they are applied to the selection of methods of surfacing as opposed to design of lay-out, is to ignore the pneumatic-tyred traffic altogether, except in the case of exceptional counts, and to set arbitrary limits for the total weight that each group of specifications, viz., surface dressings, thin carpets, medium carpets, slabs, etc., can be expected to carry without the maintenance charges becoming uneconomical. (The writer considers that total tons as taken above is of more value than tons per yard width owing to the fact that a considerable proportion of the surface of most roads is not utilized by steel-tyred traffic.) This system is, however, a very arbitrary one and with the advancement of the science of road making, as marked in India by the existence of this Congress, it should be possible to devise a more accurate method of applying traffic census figures in the design of road surfaces.

8. The new Test Track at Alipore is to be used, it is understood, primarily to test, under as near an approximation to actual conditions as can be devised, the wear of different types of road stone, both in waterbound macadam and as blindage for surface dressing under steel and pneumatic tyres. Presumably a natural development of this will in time be the testing of different types of binders, carpets and slabs. Would it not be possible, while this is in progress, further to extend the scope of the Track to embrace the analysis of the comparative wear caused by the main types of loading, viz., on steel tyres and on pneumatic tyres, met with in this country? That this has not been done, to the best of the writer's belief, in England is probably due to the fact that wheel loadings in England, and on the Continent, are largely of types which can be reduced to an easily comparable basis. The problem of the steel-tyred, loose axled, heavily laden, animal-drawn cart is essentially Indian, and the correlation of the wear caused by this type of traffic to the wear caused by other types of vehicles using Indian roads is a problem to be solved in India. If the Test Track could be used as a medium to establish "co-efficients of wear" for steel-tyred and other types of traffic it might be possible to reduce traffic statistics to a formula based on the volume of different types with their "wear co-efficients" which would produce a "wear factor" which could be considered in the light of the wear results obtained on the Test Track for the various specifications tested.

9. There are two further points which have bearing on the consideration of traffic statistics in so far as wear results are concerned, which the author would like to touch upon before concluding. These are camber and width.

10. The question of the most suitable camber to adopt when improving road surfaces is one which is receiving considerable attention in Madras Presidency just now. Opinions vary, but it seems to the writer, that where there is any considerable volume of animal-drawn traffic, the camber of the road should be as flat as possible, consistent with the adequate drainage of surface water. The reason for this is that, when the camber is steep, on district roads, bullocks have a definite tendency to hug the crown of the road, with consequent tracking and exceptional wear alone defined wheel-tracks. Near towns and elsewhere where there is continuous, or nearly continuous traffic in both directions, the bullocks cannot hug the crown but if the camber is steep, they will tend to the reverse, to hug the edges of their respective sides of the road, with similar tracking and exceptional wear along these tracks. If the surface has a comparatively flat camber, there is less advantage for the single line of bullock-carts, in hugging the crown ; and less centrifugal throw towards the edges for the double line of traffic. In consequence, the bullocks use a greater area of the road laterally, with more widespread and less damaging wear.

11. In regard to road widths, the question is a thorny one, and closely allied with the question of the provision of separate and differently surfaced lanes for slow-moving and fast-moving traffic. It would seem that where ease of travel is not the most important factor, i.e., such as roads where the main problem is to provide a suitable surface to accommodate traffic consisting largely of bullock-carts, wide roads give more scope than narrow ones for tracking and accelerated wear along the tracks, which necessitates the renewal of a much larger area of the road surface than merely the width of the wheel tracks. On one of the main arterial approaches to Madras City, the road has a surfaced width of fifteen feet only, yet the wear here compares very favourably with other similar but much wider stretches of road, where the bullock has betaken itself, as it cannot do on the narrow road, to tracks at the sides. It would be interesting to have a length of heavily trafficked road kept under observation in a number of sections, with the widths in each section reducing from, say, thirty feet in the first to fourteen feet in the last. The comparative wear in each section could then be considered in the light of initial cost and convenience to traffic.

Discussions on Paper No. H.

Mr. Ian A. T. Shannon (Author): It is with some diffidence that I introduce a paper which is so devoid of information. When writing it. however, I did so not in an endeavour to impart information but in the hope that it would give rise to a discussion from which information could be gleaned.

There are two particular reasons that have prompted me to send in this brief paper. Firstly. I had a conversation with Mr. K. G. Mitchell when he visited Madras a few months ago, in the course of which I mentioned to him the points that I have now included in this paper. Within a few days of his return to his headquarters. I had a notification from Mr. Jagdish Prasad that my name had been put down for a paper for this Congress. I was, one might say, given no option.

Lastly some years ago. I was called upon to give technical evidence in what was known a "The Malabar Bus Case." It was a criminal case and I spent four hours in the witness box. For two of the four hours the prosecuting counsel tried to make me swear that buses do more damage to a road than bullock carts, and for the remaining two hours the defence counsel endeavoured to make me swear that bullock carts do more damage to roads than buses do. I was not able to satisfy either of these gentlemen but the occasion has left me with a keen desire to know more about the relative damage done by these main types of traffic and their various combinations and I sincerely hope that this paper will lead to a discussion which will give information on these points.

Mr. A. Lakshminarayana Rao (Madras): I beg to raise some points. Is the intensity of traffic one of the factors in the destruction of roads or will the same volume of traffic during a shorter period have a greater destructive effect on road surface than when it is distributed over a longer period? This question decides whether traffic census should be taken when the traffic is high or of average intensity. It is apparent that the intensity of traffic destroys roads and not the average traffic over long periods as might have been observed by most of us just after festivals when there is heavy traffic and the roads are easily destroyed. Is it then necessary for us to find the peak traffic on the road during the heavy season or is it the average traffic that counts in the matter? Because we design our roads for a particular traffic, this has become all the more necessary. There are places which will also be in your view, where the traffic during the intensive season will be about a thousand tons and during the lean periods about hundred tons. Is it desirable to design a road for 100 tons or for 1,000 tons? I beg to be enlightened on these points by members.

Captain R. C. Graham (North-West Frontier Province): I have no criticisms to offer about this paper, but I want to tell you what we have tried in the North-West Frontier Province. We have made our roads absolutely flat. That has been more successful. However, the berms must conform with the outline of the roads and it is a difficult matter to make the local gangs believe that the berms will have to be built to conform with the slope of the road and the contours of the locality.

Mr. C. D. N. Meares (Calcutta): In para 8 of the paper it is stated that the new Test Track at Alipore is to be used to test the wear of

different types of road stone; both in water-bound macadam and as blindage for surface dressing under steel and pneumatic tyres. The Alipore Test Track is not meant for high speed motor traffic but only for the testing of bullock-cart traffic.

Mr. T. R. S. Kynnersley (Bombay): We as engineers must study the psychology of the bullock. If you are going to make a special track for this animal to walk on you must make it in such a way that he will choose it naturally. The bullock will be with us for many years to come, it is therefore necessary to consider all aspects of this question. Every inch of roadway means money and we must do all we can to save that little bit of extra road which is never used. The bullock will always tend to keep some 18 inches nearer the centre of the road than the edge but if the track is made of concrete. 18 inches of concrete may seldom be used. I put this to you as a problem. I have no solution. How are we going to get the maximum benefit from the roads we make. Perhaps the edge outside the concrete might be made the same colour for a width of 12 inches or so; this would camouflage it in order to make the bullock go nearer the edge of the concrete than he does at present. In nearly every case the bullock walks in front of the wheel of his cart. You may say that this will lead to the formation of tracks. Bullocks tend to follow immediately behind the cart in front and so tracking is usual. I have observed, however, that in spite of certain wear or rutting taking place in the first few years the rate of increase of rutting slows down considerably as the ruts get filled with bullock droppings and the dust and dirt from the road. This makes a pad which definitely slows down the rate of wear. This can be seen on the concrete strip near the station at Lucknow. I feel sure that the best roads of the future will be those in which the bullock-cart proceeds on either side leaving room in the centre for buses, lorries and motor cars.

Mr. L. B. Gilbert (Chairman): Before calling upon Mr. Shannon to reply I should like to say that the Test Track at Alipore (Calcutta) is meant chiefly for testing the value of different aggregates and binders.

Mr. Ian A. T. Shannon (Author): There are one or two points which have been raised to which I should like to reply. Mr. Lakshminarayana Rao is uncertain whether it is the peak load or the average load of traffic that should be taken into consideration, when considering traffic statistics for the purpose of designing a road surface. Both peak and average loads should, I consider, be taken into account. If at any time wear factors can be established and incorporated in a formula, then the difference between the peak and average loads might be taken into account as some form of factor of safety.

Captain Graham mentioned that in the North West Frontier Province they have been reducing the camber on some roads and even abolishing two way falls in favour of a straight slope across the road. This not only has an effect on the road design but has a bearing on the "psychology of the bullock" to which Mr. Kynnersley has referred. It is frequently said that you cannot make a bullock do what it does not want to but are we sure that the bullock *does* want to travel always in one line? May it not be that this tendency is in fact caused by the camber of the road? Experience seems to show that if the camber of the road is low the bullock will travel over a greater area of the road surface than just tracks in the centre or at the sides.

Mr. Meares has told us that the Test Track at Alipore (Calcutta) has no provision for a fast-moving traffic test. In this case it will be impossible to take up my suggestion that the Test Track should be used to correlate the difference in the wear of bullock-cart and fast-moving traffic. I am sorry that this is so as I recently had an opportunity of visiting the Netherland Indies Road Research Laboratories at Bandeong in Java and from what I saw there, I feel that problems of this nature certainly could be tackled by a track in this country.

Mr. S. G. Stubbs (President) : I have pleasure in proposing a vote of thanks to Mr. Gilbert for having presided over this group meeting acclamation.

The Congress adjourned at this stage to reassemble on the following day (January 6).

Thursday, January 6, 1938.

PAPER E.

The Congress reassembled at the Address Hall, Osmania University, at 9-30 a.m. on Thursday, January 6, 1938, with Mr. S. G. Stubbs, President, in the Chair.

Mr. S. G. Stubbs (President) : I call upon Colonel G. E. Sopwith to take the chair during the discussion of the next group of papers.

Colonel G. E. Sopwith took the chair.

Colonel G. E. Sopwith (Chairman) : I call upon Mr. Jagdish Prasad to present the Paper on "Safe Wheel Loads for Indian Roads" by Messrs. K. G. Mitchell and Jagdish Prasad.

The following paper was then taken as read :—

PAPER No. (E).

ERRATA.

Page 2 (*e*), line 20.
For "effect" read "affect".
Page 3 (*e*), line 30.
For "... pressure that the old ..."
read "... pressure. The old ..."
Page 12 (*e*), line 2 below figure 1.
For "7·34" read "6·90".
Page 12 (*e*), line 3 below figure 1.
For "17·79" read 16·70"

PAPER No. (E.)

SAFE WHEEL LOADS FOR INDIAN ROADS.

BY

K. G. Mitchell, C.I.E., I.S.E.,

AND

Jagdish Prasad, C.E.

In Paper No. 39 on "Optimum Weight of Vehicles on Extra-Municipal Roads," read at the Third Indian Roads Congress it was pointed out that the limitation of gross-laden weight of motor vehicles was necessary in the interest of roads and a limit was suggested as a reasonable compromise between what the motor industry required and what the roads could carry. This was expressed in terms of gross-laden weight for a two-axled vehicle in the then existing conditions of speed obtaining and the possibility of their control and reduction. The gross-laden weight was used as conveying the general idea in the belief that the distribution of weight between axles was well-known to those interested. The multiple axle vehicle was so uncommon that it was not referred to. Much of the criticism of the Paper was directed at its failure to state the obvious in these directions. It was also criticised because it did not refer to bullock-cart loads.

The present Paper attempts to set out the arguments more in detail. It assumes, moreover, that it will be possible to regulate speeds by the use of governors, and it endeavours to show the effect on the generality of Indian Roads of a four ton axle load (which means a 5½ ton gross load on the ordinary two-axled chassis) at probable speeds. If the movements of motor transport and the trade in vehicles is not to be hampered by a host of local restrictions the subject must be approached not as one concerning any particular province or state but as effecting the whole of India, in the way of a reasonable balance between the requirements of motor transport and the cost of road construction and maintenance.

It is true that all over India roads have been improved above the standard of what we may generalize as ordinary water-bound macadam but, with the exception of one or two provinces, only in short lengths. To attempt at this stage to vary permissible loads and speeds on these isolated lengths (which have been improved for local concentrations of all classes of traffic), would be to invite chaos. It is true that there are many lengths of metalled and laterite roads much below what we are taking as our average condition. The raising of these lengths of inferior road to the average so as gradually to do away with local restrictions is a reasonable conception. It is the furthest that India could go at present in the direction of "making the roads suit the traffic and not *vice versa.*"

Having regard, therefore, to the stage reached by motor transport on the one hand and by the general condition of roads on the other it is proposed to examine the effect of a 4-ton axle load. In relation to the road as distinguished from its bridges and with due regard to considerations of speed for the same total tonnage of traffic moved the number of axles could be multiplied without detriment. But the question of the strength of existing bridges then comes in and the proposal to use multiple 4-ton axles must be considered from that angle.

The permissible wheel load depends upon the strength of the existing roads and the bearing capacity of the earth sub-grade upon which they are founded. Consideration of failures due to heavy wheel loads indicates that not only the road crust but also the subgrade is affected. This Paper is concerned with the stressing of the road structure rather than with the abrasive and destructive forces at the surface. Apart from the impact effects on the road structure the faster a vehicle moves, the greater the stresses in the surface layer which tend to losen and break down the structure. In wet weather with water standing in potholes the water hammer effect is severe and large particles of stone are ejected with the water violently displaced by a fast-moving wheel. The ruts and potholes get deeper and not only is the effective cover of the macadam much reduced in thickness, but the sub-grade is softened by water seeping through from standing in the ruts so that the thinnest part of the crust has the least support. Abrasion will be referred to later.

Impact.—Impact is affected by the roughness of the surface, the nature and condition of the tyres, the speed of the vehicle and the wheel load. The ratio of sprung to unsprung weight and the flexibility of springs also effect the magnitude of impact but are not of great importance. How the nature of tyre effects, impact will appear from the fact that impact force is a product of mass and acceleration. The greater the acceleration, i.e., the greater the rate of change of velocity, or the shorter the time and distance over which the velocity changes from maximum to zero, the greater will be the force of impact. A steel-tyred wheel produces greater impact than a pneumatic-tyred wheel when falling on the road under gravity because the velocity of the former is brought to zero in a very small interval of time and space while a pneumatic-tyred wheel is brought to rest in somewhat longer time and space owing to the deflection of the tyre.

Measurements of wheel impact, produced by a trailer on a rough road surface which needed reconstruction, were carried out in 1932 at Harmondsworth at speeds between 14 and 27 miles per hour and the following conclusions were drawn[*] :—

(1) "Blows of the magnitude of 2 × static load may be expected with high-pressure pneumatic tyres, though these blows are unlikely to exceed 2¼ × static load."

(2) "Blows of 1¾ × static load are closely approached with low pressure pneumatic tyres, there being a number of blows exceeding 1½ × static load."

(3) "Blows of 3¼ × static load may be expected in isolated cases with solid tyres, and it is not unusual for blows to exceed 2¼ × static load."

Some of the deductions from impact tests carried out by the United States Bureau of Public Roads with a heavy motor 'bus fitted with balloon tyres were † :—

"The frequent reactions for rough surfaces amount to about 1·5 times the static wheel load."

"Even the smoothest roads produce frequent reactions of from 1·1 to 1·2 times the static wheel load."

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* Ministry of Transport. "Experimental Work an Roads," Report for the year 1932, (H. M. Stationery Office, London.)

† Vide "Public Roads," Washington, Vol. 13. No. 9, November 1932.

"A few reactions amounting to twice the wheel load may be expected for each mile of rough surface."

The influence of vehicle speed on impact is illustrated by the following table* which gives the general maximum reactions produced by twenty-eight natural rough spots on highways.

Speed miles per hour	Impact Reaction Pounds	Ratio of total reaction to Static Load.	Speed. miles per hour.	Impact Reaction Pounds	Ratio of Total reaction to static Load.
		per cent.			per cent.
0	8,000	100	40	21,800	273
10	11,000	138	50	23,500	294
20	15,200	190	60	23,700	296
30	19,000	238	70	23,700	296

Although impact reactions on roads will under certain conditions become maxima at a speed of about 40 miles per hour or even less, the ruling tendency is for them to increase with speed. Tests carried out at the National Physical Laboratory (England) in 1932, suggested that "increase in speed increases the number of impacts as well as both their average and maximum values, and the influence of speed is more pronounced for tyres of greater stiffness."

With the object of correlating impact to tyre equipment and speed, tests were carried out by the United States Bureau of Public Roads† with wheel loads ranging from 3,000 to 10,000 pounds to determine the speed at which any particular type of tyre would produce the same impact reaction as a pneumatic tyre at a given speed. The following figures which were obtained show the fractions of the speed with pneumatic tyre equipment at which nearly equal impact will be caused by other tyres :—

Type of Tyre		*Speed for Equal Impact*
Pneumatic	...	100
New Cushion	...	55
New Solid	...	40
Worn Solid	...	20

The table below, from the same source, gives the relative speeds for nearly equal impact reactions.

Tyre equipment.	Relative speeds in miles per hour					
Pneumatic	40	35	30	25	20	15
New Cushion	22	19	16	14	11	8
New Solid	16	14	12	10	8	6
Worn Solid	8	7	6	5	4	3

It may be inferred from these results that if vehicles equipped with pneumatic tyres can be allowed to travel at, say, thirty miles per hour those with solid tyres should be limited to twelve miles per hour for the same impact.

Speed.—But impact is not the only effect of speed. High speeds imply rapid acceleration and relatively sudden braking which cause excessive wear of water-bound surfaces as well, of course, wear and tear of the vehicle. It has already been pointed out that heavy motor vehicles travelling at high speed produce large tangential forces in the road. The

* "Public Roads," Washington, W.C., Volume 13, No. 9, November 1932.

† "Public Roads," Washington, Volume 11, No. 7, September 1930.

greater the load the greater is the tractive resistance and the greater the tangential forces which cause damage and corrugate macadam and gravel roads. The tractive resistance and, therefore, the destructive effect of a motor vehicle increases with speed. An axle load of 1·17 tons moving at 15 miles per hour affords almost the same tractive resistance as an axle load of 8 tons travelling at 3 miles per hour (*vide* "Procedings Institution of Civil Engineers," Volume 237, *p.* 68).

The foregoing statements merely emphasise what all Road Engineers know, which is that reasonable control of speed of motor vehicles is necessary in the interest of the road. It is also so from the point of view of the vehicle and the safety of passengers, pedestrians, and other road users.

A plea is often made that reduction of speed reduces the daily mileage and hence the earning capacity of a motor vehicle. But a closer examination of traffic conditions, particularly in India, will show that the relations between maximum speed and the mileage that can be done in a fixed period is by no means a straight line relation. For example, a man walking steadily at a speed of four miles per hour can normally cover four miles in one hour ; a cyclist riding at a speed of twelve miles per hour is probably able to do eleven miles in an hour ; a motor vehicle with a maximum speed of twenty miles per hour possibly does about eighteen miles in an hour ; at a maximum speed of thirty-five miles per hour it will do perhaps twenty-eight miles in the hour, but to add ten miles per hour to the average speed above that it has to increase its maximum speed by double that amount. Conversely, a reduction of ten miles an hour in maximum speed may only mean a reduction of half that amount in average speed. The point is obvious and need not be laboured. The output of a motor vehicle in ton-miles is not therefore directly proportional to maximum speed. There are others at least equally important factors which in practice affect the daily ton-mileage, for example, the time spent in loading and unloading, the number of stoppages on the way for various reasons and the condition of traffic on the roads. Hence a reduction of the maximum speed from forty to thirty miles per hour will not reduce the earning capacity of the vehicle *pro tanto*. It is indeed doubful if any one could show that a reduction of this amount would appreciably affect carrying capacity at all. It would certainly save in the maintenance of the vehicle and in the road bill.

Effect of wheel load on subgrade.—We now come to a consideration of the effect of wheel loads on sub-grade. Different soils have different load-bearing capacities and the supporting power of the same soil varies with its moisture content and other less important factors. Experiments have proved and experience has shown that an increase in moisture content beyond a certain point will decrease considerably its load-bearing capacity. When considering wheel load distribution, the supporting power of a particular soil in its weakest state should be taken as its safe bearing value. It has already been suggested that during the rains the sub-grade capacity may be impaired because the macadam crust is pervious and weak, particulary in the ruts. The Public Works Department Handbook, Bombay, gives the following values of safe bearing capacities of certain soils for building foundations :—

Description of soil.		Safe load in tons per square foot.
1. Soft, wet, pasty or muddy clay and marshy clay.	...	0·25 to 0·33
2. Black Cotton soils	...	0 50 to 0 75
3. Alluvial earth and loams (clay 30 to 70 per cent of sand)	...	0·75 to 1·50
4. Moist clay	...	1·00 to 1·75
5. Loose sand in shifting river-beds ...	...	1·50 to 2·50
6. Sandy gravel or *kunkur* ...	...	2·00 to 3·00

Taking the lower limits for reasons already stated, the capacity of different road soils may be stated as being :—

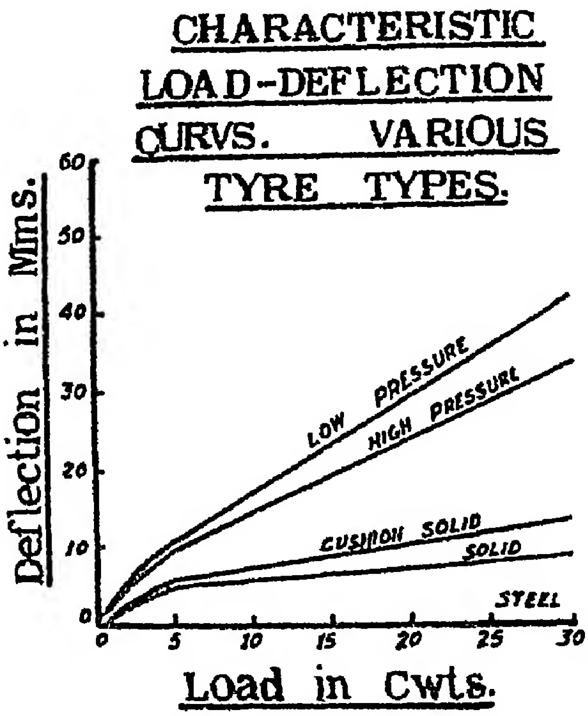
Description of soil.	Safe load in tons per square foot.	Safe load in pounds per square inch (approximately)
1. Soft, wet, pasty or muddy clay and marshy clay	... $\frac{1}{4}$	... 4
2. Black cotton soils ...	... $\frac{1}{2}$	... 8
3. Alluvial earth and loams ...	... $\frac{3}{4}$	... 12
4. Moist clay ...	... 1	... 16
5. Loose sand in shifting river-beds	... $1\frac{1}{2}$	... 21
6. Sandy gravel ...	... 2	... 32

Ultimately it is the sub-grade that carries the load which must be distributed and reduced to an intensity which the particular material can carry. This is done in two ways : first by the tyre of the vehicle and secondly by the road-crust. We need only consider pneumatic tyres for motor vehicles. Solid or cushion tyres should be prohibited except in special localities where roads are abnormally strong and speeds can be restricted in practice as well as by printed regulation. Pneumatic tyres are of two main classes, i.e., standard or high pressure and balloon or low pressure. (The former used to be known as balloon and the latter as extra low pressure that the old extra high-pressure tyre has practically disappeared).

The distribution of pressure depends on the area of wheel contact, which in turn depends on the width of tyre and length of contact along the road. In case of pneumatic tyres, the size and shape of the road contact area depends on the magnitude of the wheel load, the air pressure in the tyre, and on various physical properties of the tyre, such as, condition of tread, casing stiffness, size, etc. Tyres of the same size and type but of different manufacture may not produce exactly the same contact area under equal loads due to slight variations in the stiffness of the casing or difference in tread designs. Which of the two types of pneumatic tyres will be used with a given wheel load in the future is difficult to foretell because the selection of any one type will depend on certain factors, such as, the initial cost, the life of the tyre in service, tractive resistance produced (on which depends the fuel consumption) and riding comfort. It may be assumed that the life of both high-pressure and low-pressure tyres of equal load bearing capacity is the same. Hence, so far as commercial vehicles are concerned the owners will naturally consider the initial cost and the tractive resistance before deciding the class of tyre they should fit to their vehicles. The owners of private cars will perhaps give preference to riding comfort over everything else. For wheel loads up to 2,650 pounds on a single tyre or 5,300 pounds on twin tyres, the high-pressure equipment is cheaper than the low-pressure one as will appear from the following data which have been obtained from Messrs. Dunlop Rubber Company's price list No. 22.

Maximum load carried by Tyre	Size and type of Pneumatic Tyre	Cost of Tyre		Cost of Tube		Total cost		Remarks.
		Rs.	A.	Rs.	A.	Rs.	A.	
1,850 pounds	6·50—20 Low Pressure	80	4	10	12	91	0	*Can carry up to 2,000 pounds
	30 x 5 High Pressure*	78	4	9	12	88	0	
2,650 „	7·50-20 Low Pressure	119	4	14	12	134	0	
	32 x 6 High Pressure	119	4	12	8	131	12	
3,300 „	9·00-18 Low Pressure	152	4	17	8	169	12	
	34 x 7 High Pressure	176	8	14	12	191	4	

As wheel loads in excess of 3,300 pounds are not likely to be used on Indian roads, the use of high-pressure tyres will obviously be economical in the first cost. Because of its smaller width, the high-pressure tyre produces less tractive resistance than the low pressure tyre and consequently the use of high-pressure tyres will result in slight economy in fuel consumption. So far as the roads are concerned, the high pressure tyre produces a smaller road-contact area and consequently greater intensity of pressure than the low-pressure tyre. The difference in the impact produced by the two types of tyres is not great as will appear from the following load deflection curve reproduced from "Proceedings of Indian Roads Congress," Volume I, *p.* 195. But the tractive resistance and therefore the destructive capacity so far as the water-bound roads are concerned, is greater with low-pressure tyres than with the other type. As a considerable milage of roads in India is water-bound and is likely to remain so, it will be in the interest of roads as well as motor transport if high-pressure tyres are used on commercial motor vehicles. It would not matter much if private cars continue to use the low-pressure tyres for the sake of riding comfort because cars, which usually do not have axle loads greater than 1½ tons do not produce the same pressure on the road when travelling at speeds of 40-50 miles per hour as, say, a 4-ton back axle of a commercial truck travelling at 25 miles per hour. In subsequent paragraphs, in wheel load distribution calculations, the high-pressure tyre has been considered.



PRESSURE DISTRIBUTION.

By courtesy of Messrs. Dunlop Rubber Company (India) Ltd., we have been able to obtain impressions of certain high-pressure pneumatic tyres under varying loads, *vide* figures 1, 2 and 3 (size reduced). It will be noticed that the imprints are almost elliptical in shape and that the contact area increases with the load.

The distribution of pressure through the metalling may be obtained by either of the two following methods :—(i) by projecting downwards the road contact boundary of the ellipse at 45 degrees through the road crust, thus obtaining at the sub-grade an ellipse of distribution having major and minor axes greater than those of the contact ellipse by $2t$, where t is the thickness of the crust; (ii) by assuming the road contact area to be a circle of area equal to that of the ellipse and determining an equivalent radius, r, the area of distribution on the sub-grade being circular, the radius of distribution circle being $(r+t)$. The first method is suitable for single tyres and the second is more convenient in case of twin tyres when the area common to the circles of distribution formed at the base of the road crust has to be deducted from the total area of the two circles.

There is no fixed relation between the wheel load on a pneumatic tyre and the area of road contact produced, but within short range of values with which we are for the present concerned an approximate relation has been obtained for high pressure tyres. From the values of wheel loads and corresponding contact areas for a 34-inch by 6-inch tyre given on page 94 of the report of the Road Research Board (England) for the year ended 31st March, 1936, the following relation has been deduced :—

$$L = 32{\cdot}4\ A^{1{\cdot}3}$$

where L is the wheel load in pounds and A the contact area in square inches. The data supplied by Messrs. The Dunlop Rubber Company (India) Limited for 32-inch by 6-inch tyre give the following relation :—

$$L = 50\ A^{1{\cdot}2}$$

For high-pressure tyres and for wheel loads ranging from, say 1,600 pounds to 4,300 pounds any one of the above formulæ may be adopted, the values obtained from them differ by about 2 to 3 per cent.

A series of curves have been drawn, *vide* figures 4 and 5, showing for wheel loads of 1 ton, 1½ tons, 2 tons and 3 tons with 50 per cent impact allowance and also with 100 per cent impact allowance, the relation between the thickness of crust and the pressure produced on the sub-grade. Wheel load of one ton has been assumed to be transmitted through a 32-inch by 6-inch high pressure tyre, that of 1½ tons through a 34-inch by 7-inch tyre, the 2-ton load through twin tyres 32 inches by 6 inches spaced 8½ inches centres and the 3-ton wheel load through twin tyres 34 inches by 7 inches also spaced 8½ inches centres. It will be seen from the graph (figure 5) that for water-bound macadam roads built over alluvial earth and loam, having a safe bearing capacity of 12 pounds per square inch a crust of 10 inches is required for a wheel load of 1½ tons transmitted through a single tyre and a little over 10 inches for a wheel load of 2 tons transmitted through twin tyres.

It will be noticed that 2-ton wheel load on twin tyres (32 inches by 6 inches) and 1½-ton wheel load on single tyre (34 inches by 7 inches) produce nearly the same pressure on the earth base. But the fact must be remembered that twin tyres cause greater deterioration of the metalled surface than single tyres, because of the space between the two tyres where air currents and eddies are produced which disturb the blinding material and road metal. Twin tyres produce greater impact than single tyre under similar load, speed and road conditions. The sectional depth of the single tyre is greater than that of twin tyres of the same

type and load carrying capacity. Because of this the deformation is greater and hence the impact force is less. But twin tyres cost much less than a single tyre of the same load-bearing capacity and are, therefore, popular.

Cement Concrete Roads.—The remarks made above relate to the "flexible" type of road and do not apply to the rigid type of pavement such as cement concrete, because in the design of the latter type soil support is not considered to be uniform. Dr. Westergarrd's method* of computing stresses in concrete road slabs takes into account the reaction of the subsoil per unit area for unit deflection of the slab and also the comparative stiffness of the slab and the sub-soil. Although his method is considered to be very scientific and the values obtained with it tally very closely with actual road tests, the formulæ are a bit complicated. In "Concrete Road Design" by F. T. Sheets, the author has given simple emperical formulæ for the design of concrete road. The results of his formulæ "so closely approximate computations made by Dr. Westergarrd's methods and also actual measured stresses that the percentage of error under the critical range of wheel loads is negligible." Sheet's formula for road slabs without longitudinal shear reinforcement is—

$$S=\frac{2{\cdot}4\ W.c}{d^2}$$

for pneumatic tyres,

where S = Safe working stress in concrete in flexure (taken as 350 pounds per square inch i.e. 50 per cent of the ultimate flexural strength)

W = Wheel load in pounds

C = Coefficient of sub-grade support (for values of C, *see* figure 8)

d = depth of road slab of uniform thickness, in inches.

The following values have been obtained from Sheet's formulæ.

Safe bearing capacity of soil.	Depth of concrete slab in inches required for wheel loads of			Remarks.
	1 ton	1½ tons	2 tons	
4 pounds per square inch	4·11	5·05	5·81	Safe for marshy soils.
8 ,, ,, ,, ,,	4·00	4·90	5·64	Safe for black cotton soil.
12 ,, ,, ,, ,,	3·85	4·75	5·46	Safe for alluvial earth and loams.
16 ,, ,, ,, ,,	3·78	4·61	5·35	Safe for moist clay.
24 ,, ,, ,, ,,	3·68	4·50	5·20	Safe for loose sand in river beds.
32 ,, ,, ,, ,,	3·56	4·38	5·05	Safe for gravel.

Curves obtained from these values are shown in figure 7. For wheel loads transmitted through solid tyres these values should be increased by about 12 per cent.

* "Public Roads" Washington, Volume 7, No. 2, April 1926.

It may here be pointed out that in accordance with the researches on the behaviour of concrete under repetition of stress the useful life of concrete is shortened in proportion to the frequency of overloading. Concrete becomes fatigued in tension and failure occurs if flexural stresses amounting to more than 50 per cent of the ultimate modulus of rupture are repeated continuously*. Consequently in the formulæ quoted above the safe working stress in concrete has been taken as half of the value of ultimate modulus of rupture.

Effect of Iron-Tyred Wheels.—This discussion will perhaps be incomplete without a reference to the action of the iron-tyred bullock cart. It is generally agreed that heavy weights carried on vehicles with narrow tyres cause considerable wear on almost all types of hard surfaces but on asphalt roads the action of iron tyre is particularly damaging. It is consequently necessary to restrict either the width of tyre for a particular load or *vice versa* so that the pressure transmitted on the road surface is not excessive. It will be observed that the greater the width of the tyre the less the probability of uniformity of contact between the tyre and the road. Therefore, the load per inch width of tyre should be less in the case of wide tyres than in the case of narrow tyres. The following table taken from "Indian Roads," No. 4, March 1933, gives the loads and tyre widths of typical two-wheeled bullock or buffalo carts in use in different parts of India.

* *Vide* "Concrete Road Design" by F. T. Sheets, Portland Cement Association, Chicago.

LOADS AND TYRE WIDTHS OF TYPICAL TWO-WHEELED BULLOCK OR BUFFALO CARTS.

	Weight of loaded Cart.	Diameter of Wheels.	Width of Tyre.	Maximum load per inch width of Tyre.
	POUNDS.	FEET.	INCHES.	POUNDS.
MADRAS :—				
Trichy Circle	1120 to 3700	...	2	840
Madras Circle	963 to 2016	3 to 5½	1¾ to 2¼	870
Coimbatore Circle... ..	1013 to 7325	...	2 to 3	1220 *
Bezwada Circle	2016 to 2021	...	2	870
BENGAL :—				
Calcutta	3584 to 4928	6	1¼ to 2	1230
Outside Calcutta	3584 to 4928	5	1¼ to 1¾	1100
Northern Circle	672 to 2180	3½ to 4	1½ to 2¼	500
UNITED PROVINCES :—				
Benares	7168	4½	2	1790
Allahabad	7280	5	3 **	1210
Jhansi	3711	4½	2	930
BAREILLY :—				
(1)	4114	4	2	1030
(2)	2912	4	3	480
(3)	1114	4	1½	1510
AGRA :—				
(1)	6370	4½	1¼	1500
(2)	4114	4¾	3	770
Fyzabad	4480	4 to 6	1½ to 2	1120
Cawnpore .. .	4484 to 6100	4½ to 5	2 to 2½	1220
Lucknow	4480	4	2 to 3	1120 †
PUNJAB:—				
Lahore District	3315	5	2	830
Gujrat District	4111	4½	2	1030
BIHAR AND ORISSA :—				
(1)	1658	4	2	410
(2)	2012	4½	1½	970
CENTRAL PROVINCES :—				
Akola	2016	3½ to 4	2 to 2¼	500
Nagpur	1080	...	2 to 2¼	420
EAST BERAR :—				
(1)	3226	...	2	804
(2)	1971	...	1¾	574
Jubbulpur	Mean of 11 observations			1000
ASSAM :—	1038	3½	3	275 ‡

* It is assumed that the heaviest cart has 3-inch tyres.

** Bearing width said to be one inch only. Full width taken in calculating load per inch width. On one inch bearing surface the load would be 3600 pounds per inch width.

† On 2-inch tyre, 750 pounds per inch on 3-inch tyre.

‡ Tyre width prescribed by rules under Assam Highways Act, 1928.

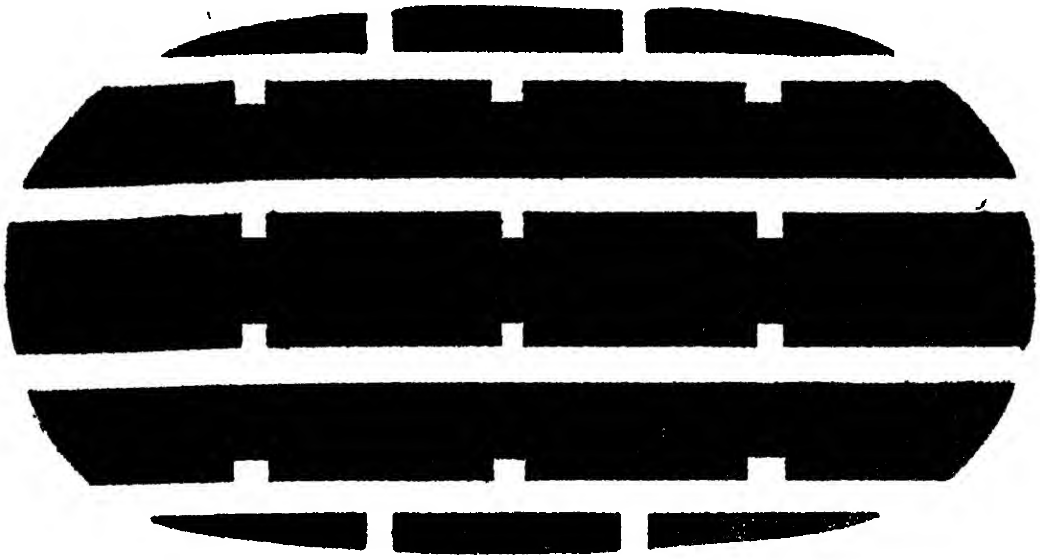
It will be noticed that wheel loads of 3600 pounds on 2-inch tyre, i.e., 1800 pounds per inch width do occur in certain parts of the United Provinces. Over and above this should be considered the effect of bent axles, throwing the whole weight on to an edge of the tyre, and the wobbling of the wheel which tends to disintegrate the surface. In England where roads are much better and stronger than what we have in India, the average permissible loads per inch width of tyre for horse drawn carts vary between 430 pounds to 695 pounds (*vide* " Indian Roads " No. 4. March 1933). For our roads the loads should be well under these.

Apart from the effect of the bullock-cart wheel on the road surface, its effect on the bearing capacity of the sub-grade may also be considered. For all practical purposes the bullock-cart wheel load may be assumed as a concentrated point load, the distribution of pressure through the road crust as conical and the area of the sub-grade over which the pressure is applied as a circle of radius equal to the thickness of the road crust. With these assumptions curves have been plotted (*vide* figure 6), showing the thickness of metal required for various sub-grade conditions and for wheel loads of ½ ton, 1 ton and 1½ tons. It will be seen that a thickness of 9½ inches of road metal is required for wheel load of 1 ton on roads passing through black cotton soils and for wheel load of 1½ tons on roads built over alluvial earth and loam.

Conclusion.—So far as the pneumatic-tyred motor vehicle is concerned, for " flexible " type of roads built over alluvial soil as commonly occurs in the plains of India, it is necessary that the crust should be 10 inches thick if wheel loads of 2 tons are permitted. As a considerable mileage of roads has depth of metal under 10 inches and as there is no likelihood of a general programme of thickening the road crust being taken up in the near future, for want of funds, the only way to allow 2-ton wheel loads on existing roads is to govern the speed of motor vehicles to ensure that the impact is reduced to a minimum practical limit. In the case of bullock-carts, a wheel load of 1 ton may ordinarily be considered as safe for existing metalled roads and for thin cement concrete slabs, but a width of tyre of 4 to 5 inches will probably be required if surface-treated roads are to have the maximum life under mixed traffic.

FIGURE 1.

32″ × 6″ R. H. S.



Total Area 23·6 sq. in.

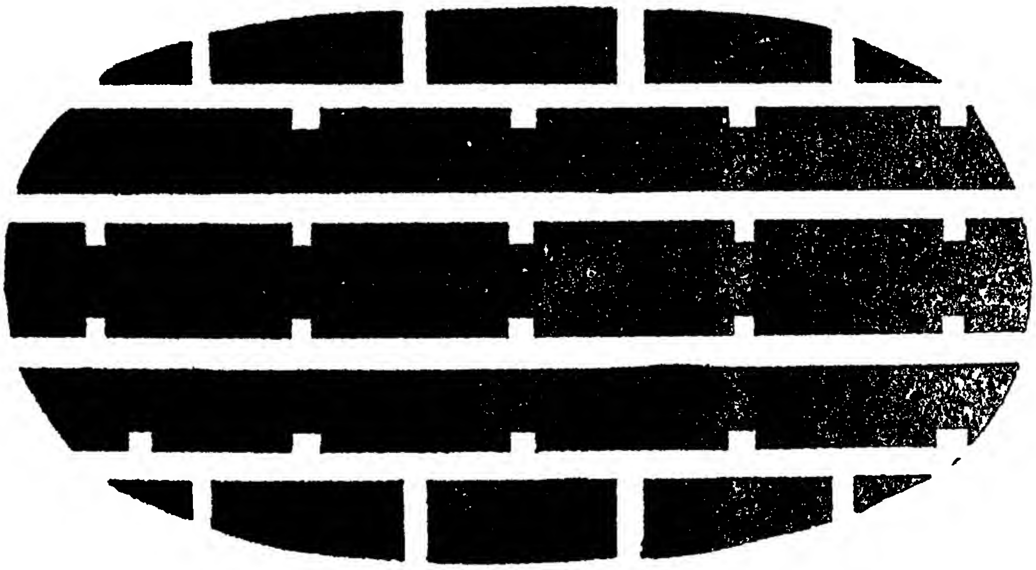
Sea 29·2% (7·34 sq. in.)

Land 70·8% (17·79 sq. in.)

Maximum Schedule load 2200 lbs. at 80 lbs./sq. in.

FIGURE 2.

32″ × 6″ R. H. S.



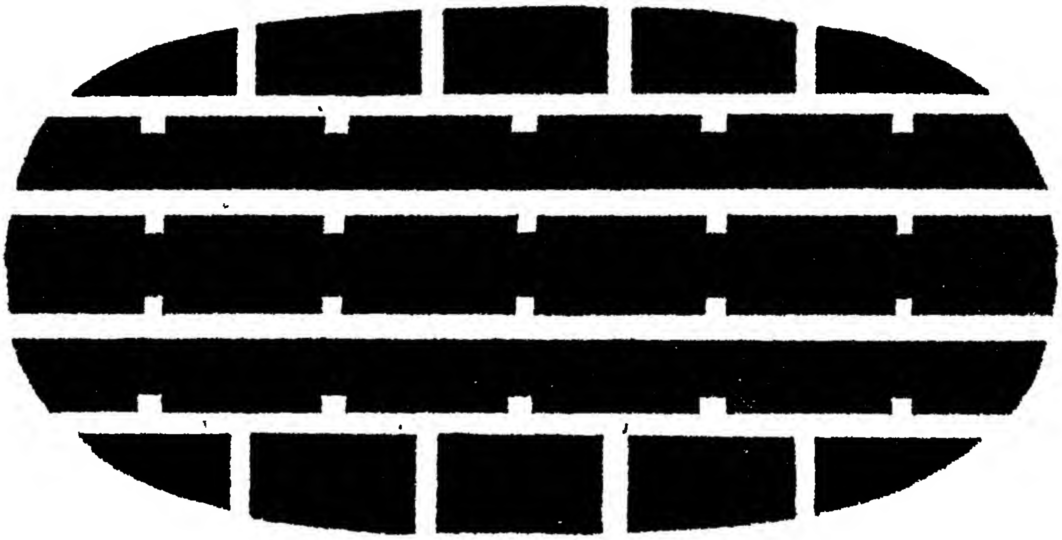
Total Area 33·6 sq. in.

Sea 29·1% (9·78 sq. in.)

Land 70·9% (23·82 sq. in.)

50% over load 3300 lbs. at 80 lbs./sq. in.

FIGURE 3.
32″×6″ R. H. S.



Total Area 43·2 sq. in.
Sea 26·85% (11·6 sq. in.)
Land 73·15% (31·6 sq. in.)
100% over Load 4400 lbs. at 80 lbs./sq. in.

Discussions on Paper No. E.

Mr. Jagdish Prasad (Author): I wish Mr. K. G. Mitchell was here to introduce this Paper. Unfortunately he had to go away to England and we are sorry he has not been able to attend this session. In introducing the paper before you I would point out that in this paper an attempt has been made to show why and to what extent the restriction of speed and loading of motor vehicles is necessary in the interest of the roads in this country. I would emphasise the point that considering the conditions in India, road mileage increase is much more important and valuable than load increase and, therefore, restriction of speed and loads is desirable with regard to the carrying capacity of our extra-municipal roads.

Mr. Raj Mohan Nath (Assam): The learned authors of this paper have advocated limitation of speed and wheel load on a road. but this of course does not limit the number of vehicles or total weight per yard width of the road.

Their calculation is further based on the initial bearing power of the sub-soil: but the bearing power of the sub-soil improves after it has been in protection for some years by the impervious carpet of macadam or gravel. On this assumption, I think, the conclusion of the learned authors is a bit too far on the safe side. We may perhaps safely allow a load of 2 tons on a crust of 6 inches as otherwise most of our roads will go without any bus or lorry.

As regards bullock-carts, it is desirable that there should be a uniform width of the tyre all over the country. But the recommendation of the authors—4 to 5 inches—seems to be a bit too much, as it will be heavy and a costly thing to poor cartmen, most of whom are agriculturists also. In Assam, though an act was passed in 1928, stressing for a uniform width of 3 inches, up till now we have got such carts only in two districts out of twelve in the province, and there has been a lot of agitation both in and outside the Council against following this sound engineering principle deviating from the time-honoured custom.

Mr. N. Dass Gupta (Calcutta): The paper presented by Messrs. Mitchell and Jagdish Prasad is a very valuable and interesting one. The authors have taken enough pains to find out the suitable thickness of the road crust keeping in view the safe bearing pressure of the sub-grade. But there are two points on which I disagree with the authors. Firstly, they hold that "twin tyres produce greater impact than single tyre under similar load, speed and road conditions." From para B-4 on Page 9 of the Standard Specifications and Codes of Practice for Road Bridges in India published by the Indian Roads Congress we find that "impact allowance . . . . due to speed is to be taken as equal to the appropriate standard live load (including single knife edge load) at the position giving greatest stress in the member multiplied by a factor I determined by the following formula :—

$$I = \tfrac{1}{2} \times \frac{65}{45 + L\,\frac{(N+1)}{2}} \quad \text{Where } N = \text{number of traffic lanes."}$$

As there is no factor in the above formula which is function of tyre-width, the impact load will be constant for the same speed and load.

Secondly, I think it is too much to assume that the bullock-cart wheel exerts a knife edge load. From the [illegible]ns published in the proceedings

of the Second Indian Roads Congress, it was found that the wheels rest on a rectangle however small its area might be. This small area when projected on the sub-grade at 45 degrees will form an appreciable area when the crust is reasonably thick and the actual pressure on the sub-grade will be much less than what the authors have calculated on the basis of conical distribution of pressure. I hope Mr. Jagdish Prasad will try to clear these two points.

Another point which I could not follow is the object of writing this paper. If it is meant for guidance of the engineers for design of water-bound macadams, it is well and good: but, if it is intended to put restrictions on the weight of motor vehicles to be allowed on the roads, specially on trunk roads and important inter-district roads, we should seriously oppose it. As I had said at the last session of this Congress, the road transport had several decided advantages over railway transport, and this form of transport should not be discouraged by unnecessary legislation in the interest of railway transport. Any restriction regarding the weight will make this system of transport uneconomical and therefore obsolete. I strongly believe that with the growth of motor transport in India, the bullock-carts will gradually and automatically come into disuse so far as carrying of agricultural produce into trade centres is concerned. Of the motor lorries and the bullock-carts, the latter cause more damage specially to painted roads and we should, in the interest of our roads and the public in general, allow the system of road transport to develop rather than destroy it by hastily putting up some bans. I do not think that an alarming number of extra heavy motor vehicles are plying nowadays on our roads and we can wait another ten to fifteen years to watch the development of motor transport which is very essential for the prosperity of India. We can come up with our legislation when a really dangerous point has been reached. However anxious we may be to protect our roads, we must not forget that all funds for road development and maintenance come from the users of motor vehicles which include a large number of lorry owners. They can rightly claim to use the roads for which they pay their annual motor vehicles tax and duty on petrol. I should, therefore, request this Congress to carefully consider this question.

But there is one point on which I concur with the authors is that the speed should be restricted with suitable speed governors and by legislation for heavy lorries. This precautionary measure will go a long way to protect our roads as it has been accepted that in the case of motor vehicles it is the speed which is more destructive than the actual load it carries.

Rai Sahib Fateh Chand (United Provinces): I think it is very necessary to limit the speed and tonnage of vehicles using the roads. In the United Provinces there was a proposal to this effect. We cannot do without such restriction. A formula should be evolved by the Council of this Congress to find out the proportion of damages attributable to speed and to tonnage respectively.

Mr. U. J. Bhatt (Bhavnagar): At the outset I should concentrate on the paper itself. The scope of this paper is very wide and on this account alone we should be very careful in making any generalizations. On page 4 (e) of the Paper reference has been made to the effect of wheel loads on sub-grade. This relates to problems of the soil. The engineer is conversant with uniform coefficients and the settlement of particles. In dealing with particles it has to be borne in mind that below a certain size of particles Stoke's Law does not apply. As the size diminishes the

particles tend to lose their chemical value. Then problems connected with moisture arise. In the paper we have been told that

"When considering wheel load distribution, the supporting power of a particular soil in its weakest state should be taken as a safe bearing value. It has already been suggested that during the rains sub-grade capacity may be impaired because the macadam crust is impervious and weak, particularly in the ruts."

If so, then why not devise ways and means of improving the sub-grade capacity. It should ultimately lead to economical maintenance of the road surface.

A great deal of work has been done in this direction by the Massachusetts Institute of Technology and in other centres in the United States of America. Because of lack or insufficiency of data we should not generalize on a few facts. As engineers we should adopt a scientific attitude. We should realize that different physical properties of soil have different effects on the bearing capacity.

Mr. W. A. Radice (Calcutta): I am not an expert on roads. But there is one point on which I feel qualified to speak. I should say that there is a danger of coming to wrong conclusions in using words like "impact" without relating them to the context. When we speak of "impact" with reference to bridges we mean something quite different from what we mean when we use this word in connection with roads. The impact effect in the case of a bridge is measured on the structure of the bridge itself. But this is quite different from the hammering blow of the wheel on the road, the effect of which blow depends on various factors like the load, the hardness of surface, the quality of tyres, etc. It has to be remembered that there is no relation between this and what Messrs Mitchell and Jagdish Prasad have referred to in their paper.

The Council of this Congress should make up a formula for arriving at the destructive effect of speed and of load. The whole paper is written on the assumption that speeds can be limited not only by roads but also by Governments! (Laughter).

Mr. Syed Arifuddin (Hyderabad-Deccan): We have all read with very great interest the Paper on "Safe Wheel Loads" by Mr. Mitchell and Mr. Jagdish Prasad. This is, no doubt, one of the most useful papers that have been read at the Indian Roads Congress and supplies very important information which was very badly wanted. No doubt, the idea was there in the minds of the road engineers that soft soils require greater thickness of road crust than hard soils. Soling of rubble stone is therefore always used at such places. The exact thickness required was not seriously considered and therefore no definite rules were framed on the basis of possible safe load on sub-grade.

There are just two points I would like to touch upon. There is a general impression that the black cotton soil can stand a pressure of $\frac{1}{2}$ to 1 of a ton and therefore, if a building is designed with this much load on the base, it will be quite safe. Against this, I can produce a number of examples which have come to my knowledge in which the pressure on black cotton soil foundation was not even $\frac{1}{4}$ of a ton and yet the buildings cracked from top to bottom very badly. If the safe load is the only point of consideration, there is no earthly reason why these buildings should have cracked. Certainly there is something more than that. We all know that the black cotton soil swells in rainy season and shrinks in summer. Cracks have been found to go as deep as 10 feet or even more. If the soil under any foundation shrinks, the only result will be that it fails to support

any weight, in other words, the foundation masonry of the building will not be supported by any reaction from below. This must result in some portion acting as cantilever and the other as beam. The cracks therefore appear from top of the roof and go downwards in the former case. In the latter case they develop from foundations and go upwards. Such cracks have actually been observed with definite and marked deflection of foundation.

There is another theory of lateral thrust put forward by some engineers but so far no facts have been observed by me to support it. This being so, I am afraid Dr. Westergarrd's method of computing stresses in concrete road slabs will not be applicable to the black cotton soil; as there will be no reaction of the sub-soil to be taken into account. Reinforced concrete slabs seem to me to be the best solution for the black cotton soil. The other alternative that may be tried as an experiment will be to give a thick layer of gravelly soil over the black cotton soil so that contact between the black cotton soil and gravelly soils may always be maintained. This might minimise the beam and cantilever action in the concrete slab.

The case of stone metal crust is different from the concrete slab. In the case of stone metal, slight depressions and cracks do not affect the roads very much. The crust will adjust itself to the shrinkage and swell up to a certain extent. But even there, if we interpose a layer of muram or gravelly soil between the metal crust and the black cotton soil sub-grade, it will be safer and economical. After putting this layer we need not give the same thickness of metal and soling as shown in the graphs; for instance in the case of impact of wheels being equal to 100 per cent of wheel load, the thickness of the crust for a 2-ton wheel load comes to 21 inches in black cotton soil and more than 24 inches for marshy soils; alluvial earth also requires 14 inches thickness. To give such thick crusts made up of metal and soling will be an expensive affair. It will be economical, if we give a layer of gravel first and lay soling and the concrete of usual thickness on top of it. I assume that for a gravelly soil the safe load will be at least equal to lose sand for which the thickness of crust is only 6 inches to 8 inches. It is worthwhile experimenting on it and find out if we can dispense with soling stones by using a base muram or gravel and consolidating it before laying the stone metal in places where soling is very expensive and gravel cheap. I am against using gravel or muram containing good deal of clay. I would prefer to use gravel or muram containing not more than 25 per cent clay for muram surfacing. But for formation of bank muram containing over 30 per cent of clay might be quite alright.

Nawab Ahsan Yar Jung Bahadur (Hyderabad-Deccan): I do not wish to speak at great length on this paper, but I want to tell you something of my experience with concrete roads in Hyderabad. In making concrete roads we cannot rely merely upon the safe loads which the sub-grade soil can stand. In black cotton soil it is not the soil which affects the concrete surface: the cracks on such surface are caused by variations in temperature and weather conditions. In the case of metalled roads where we do not wish to spend a great deal of money we can save the road surface if we isolate the road from the neighbouring area by digging trenches about 4 to 6 feet in depth on either side and filling them up with gravel or similar coarse material. This experience applies equally effectively in the case of buildings also. When such isolating trenches are dug around a building site or along the edges of a road they save the build-

ing and the road from the contracting and swelling effect of the surrounding area. Thus the isolation of the road offers an easy solution, for troubles with the surface not caused by the sub-grade.

Mr. W. L. Murrell (Bihar): At the last Congress, I was privileged to speak on Mr. Mitchell's paper which was the fore-runner of the paper now under discussion.

It must be now 8 or 9 years since my imagination was fired by a description in the "Overseas Engineer" of a Deisel-engined 8 ton laden-weight, six wheeler vehicle, with a big pay load and minimum running costs, possibly using fuel oil produced in India, which could go wherever any motor vehicle could go. I do not remember the name of the manufacturers.

It seemed that here was the very thing for India and, because Mr. Mitchell's, previous paper suggested measures which would preclude such a vehicle. I went into opposition.

Now that Messrs. Mitchell and Jagdish Prasad have come to the conclusion that loads up to 2 tons per wheel may be permitted on the average water-bound road, provided that the speed is governed, it gives me pleasure to find myself more in the same camp.

The speed-governed Deisel vehicle has already arrived and, though its laden-weight is only 4½ tons, a certain timber company prefers such vehicles to carts, even where carting is very cheap. Still further, the company's profits enable them to make a substantial contribution to the District Board for the upkeep of the road concerned.

Three improvements only remain to make the arrangements complete. These are mechanical matters which may interest motor transport experts :—

(1) Even with a special type rear axle the minimum governed speed will be 27·4 miles per hour if the engine speed is governed to the desirable 2,000 revolutions per minute. This governed speed maximum of 27·4 miles per hour is rather too high.

(2) The governing is done on the engine revolutions and not, as it should be, on the revolutions of the lorry wheels.

(3) The pay-load is too low for maximum economy. On the other hand, the six-wheeler, when travelling unladen at a fair speed, has been proved to be one of the most destructive forces on the road, owing to its great unsprung weight. The ideal is therefore an eight-ton six-wheeler with the engine placed over the differential and other such heavy unsprung gear.

There is a point in the excellent paper now under discussion, that might be discussed. It will be noted that the curves of minimum thickness of macadam-type crust required for different loadings of motor vehicle wheels (Figure 4) are based on the assumption that the very temporary pressure on the road foundation due to motor vehicle wheels should not exceed the permanent pressures allowed for buildings.

Volume 240 of the Minutes of the Proceedings of the Institution of Civil Engineers issued after Messrs. Mitchell and Jagdish Prasad submitted their Paper contains a most enlightening article "The Laws of a Mass of Clay under Pressure" by Mr. M. A. Ravenor, M.I.C.E. This article shows most conclusively that the bearing power of any soil with any appreciable content of water and colloidal matter depends very largely on the time during which the pressure is sustained. It appears that such soil does not settle under pressure until the water content has had time to escape from the regions of pressure, carrying with it some of the

colloidal matter. Ravenor mentioned, for instance, that it took 7 or 8 days for the water to be squeezed away from a cylinder only $8\frac{1}{2}$ inches in diameter under pressure so that the cylinder ceased to settle further.

It will thus be evident that the first four soils mentioned in the paper under discussion—which all contain clay and moisture—can be given much higher temporary or wheel pressure than those which the authors have given them.

It would also appear from Mr. Ravenor's paper that, if a water-bound macadam-type crust were to fail by reason of the failure of the sub-grade, this failure is far more likely to take place under the much more slowly moving cart wheels, whose intensity of pressure also is considerably greater.

However, the cheerful fact is that the 5 ton maximum vehicular load difficulty is now removed.

Mr. A. Nageswara Ayyar (Madras) : As I have already said yesterday Madras has now over 25,000 miles of metalled roads and 4,000 miles of unmetalled roads. The policy of Madras has been to increase the total mileage every year so that as large a number of people as possible can be benefited by the use of motor vehicles. The result of this at present is that practically on every road there are motor vehicles running and the people are using them to a considerable extent. In most of the districts there are by-laws restricting the load of motor vehicles to about 3 tons.

It is said that if the bullock-carts are banned the roads will last longer. I am not quite sure about this and there is one case which tells quite the contrary. In 1934 on a certain part of a trunk road the number of bullock carts per day was 437 and the motor vehicles and lorries numbered only 50. When a census was taken on the same stretch of road in 1937 it was found that the number of bullock-carts was only 80 though the total tonnage remained practically the same as in 1934. Thus, about 350 bullock carts had been replaced by motor lorries. In 1934 the condition of the road was reported as "good." But in 1937, in spite of the greatly increased expenditure on maintenance, the road was reported to be in a "bad" condition. For the development of this country it is not necessary to increase the number of heavy motor vehicles which use the roads. The *road mileage* should be increased and *not* the number of heavy lorries. Heavily loaded motor vehicles are not required in this country. The articles which require quick transport are dairy and vegetable products which have to be taken to the urban areas from the country side. There is no urgency in the transport of cereals and these can well continue to be transported by the bullock-cart. What are required are light motor vehicles to carry articles in whose delivery time is a great factor. If road mileage is to be increased it can be done only by surface painting and heavy lorries will prove an obstacle to surface painting treatment. In Madras, Public Works Department and District Board engineers are of the opinion that the maximum allowable wheel load should be only about a ton—$3\frac{1}{2}$ tons total load on ordinary roads and $4\frac{1}{2}$ tons total load on trunk roads. If these loads are adhered to we can easily maintain all our roads in good condition.

Mr. Ali Ahmed (Assam) :—In Assam we have used gravel to improve our earth roads, this is laid on clay, loam, or sandy sub-grade as the case may be. Roads with clay sub-grade behaved best while those with loamy sub-grade were next best. Roads with gravel over sand came last in

respect of wearing quality of the road surface. But when cement concrete was used for surfacing the roads instead of gravel our experience was quite the opposite. Cement concrete trackways laid direct over a clay sub-grade proved unsatisfactory. On loamy soil, (these were 4½ inches thick and 2 feet wide, the clear spacing between the tracks being 3 feet 3 inches), the tracks behaved quite well and the first cracks began to show only after two or three years' use when traffic had increased considerably. These trackways were built directly on earth without any gravel underneath or on the crown and shoulders of the roadway. The trackways did not show much deterioration when built on sandy soil, as far as cracks are concerned. The case was quite the reverse when the tracks were built on a clay sub-grade. Soon after the tracks were constructed, there were showers of rain and numberless cracks appeared. These cracks were not due to traffic load but were caused merely by the expansion and contraction of clay due to variation of its mositure content as a result of weather conditions, small hollows forming owing to shrinking of soil under the slabs which acted like a bridge, and could not support the traffic load adequately. It, therefore, appears that when choosing the surfacing material of our roads due consideration should be given to the important aspect of the properties of the sub-grade. It may be suitable for one type of surfacing but not for the other.

Mr. C. D. N. Meares (Calcutta): The previous speakers have rather stolen my thunder. The impression I get from the paper is that one must take the soil as one finds it. The authors assume that the soil is there but nothing can be done about it and what we should be concerned with is the surface only. Modern practice, however, is in favour of giving full consideration to the sub-soil and modifying it so as to improve its bearing qualities. Under normal conditions we know that a marshy soil can be improved by the addition of sand and gravel. The result would be advantageous from the point of view of both bullock-cart and motor traffic as road crusts can be thinner and a greater mileage can be constructed.

However, while bullock-carts have very little effect on a heavy crust, on a thinner crust they have a greater deteriorative effect than motor vehicles. In this connection I worked out a formula the other day which I believe is correct and which illustrates the point. The formula is

$$W^1 = W + 2R\sqrt{W \times S \times \pi}$$

Where W^1 = The wheel load of a motor vehicle equivalent to the bullock-cart.
W = The wheel load of any bullock-cart.
R = The mean radius of contact of the motor vehicle tyres.
S = The soil bearing capacity.

You will see that as we raise the soil bearing capacity we greatly increase the equivalent safe weight of the motor vehicle. The bullock-cart is there and cannot be altered, but what we want to get at is the equivalent weight of a motor vehicle to that of bullock-cart.

Working out the formula I have given above, taking an average condition where $W = 2500$ and $R = 5$, and considering even a poor sub-soil bearing capacity of 20 pounds we get

$$W^1 = 2500 + 2 \times 5\sqrt{2500 \times 20 \times \pi}$$
$$= \text{(roughly) } 6{,}500 \text{ pounds.}$$

The mean radius of contact of the average motor tyre designed to carry 6500 pounds would vary from 5 to 7 inches—an outsize, but it serves to illustrate the point.

This formula, as I have said, is mathematical and good enough for all practical purposes. As the value of S rises, W^1 increases rapidly and therefore it is unfair to penalize the motor vehicle arbitrarily without considering this factor.

I *suggest then that what we should aim at* is to pay attention to the soil. I have known roads with only a 2-inch crust which were quite successful with 7 to 8 ton axle loads because full attention had been paid to soil mechanics.

Rai Saheb Fateh Chand (United Provinces) : Can you give us an example of such a road ?

Mr. C. D. N. Meares (Calcutta) : There are not many examples of such roads in India except for a few in Sind. But there are many such roads in other countries. In one instance in Calcutta we developed a stable sub-soil by adding cinders and sand though we could not get full uniformity owing to the absence of grading machinery. We laid on this sub-grade 2½ inches premix. The surface became a little wavy but it did not break up. This practice is quite common in Batavia, Java, Sumatra and the United States of America. The illustration shows that the crust can be thin if the sub-grade has been carefully attended to.

Mr. E. A. Nadir Shah (Bombay) : You have made W too high. In previous proceedings a wheel load of 2,500 pounds is shown as carried on a 2 inch tyre. W should therefore be very much lower.

Mr. C. D. N. Meares. (Calcutta) : As regards the load factor we have to remember that no matter how wide we make the tyres of the bullock-cart, at least during 10 per cent of its journey its load is a point load. So in making calculations you have to bear in mind this *point load*. On these grounds I do not think that the figures taken for this item in the formula I have given are excessive.

The authors of this paper have given us an excellent chart showing the pressure on a road surface due to motor vehicles including an added 100 per cent for impact factor. I think it is quite unfair to saddle motor vehicles with a 100 per cent impact factor and exempt bullock-carts altogether. When a motor vehicle travels the springs and the pneumatic *tyres greatly minimise the impact, but there is nothing to minimise the* impact of a bullock-cart with its unsprung weight and its iron tyres. So a bullock-cart is guilty of much greater impact than a motor vehicle and it is therefore unfair to penalize the motor vehicle alone and let the bullock-cart go scot free in the matter of the impact as the authors have done in their paper.

Mr. S. G. Stubbs (President) : I am inclined to agree with the last speaker. Our endeavour should be to improve the soil rather than to increase the thickness of the surface. One member asked if there were any examples of roads in India with a thin metalled surface which have proved successful. Yes. There is one such road, the Grand Trunk Road north of Rawalpindi. There the soil conditions are very favourable and a 4½-inch layer of metal without soling has stood up to traffic very well indeed. Another important point which should be borne in mind, viz., that if we waterproof the surface the bearing capacity of the sub-grade *will be greatly increased as moisture will be excluded.*

Mr. E. A. Nadir Shah (Bombay) : On page 2 of the paper the minimum impact produced on smoothest roads is given as 1·1 to 1·2 times the static wheel load (bus fitted with Baloon tyres) and the

minimum impact on a rough road produced with low pressure pneumatic tyres is stated as 1¾ times the static load.

The first table on page 3 shows that impact on a rough road varies from 100 per cent to nearly 300 per cent of static load with different speeds whereas in drawing the series of curves as per figures 4 and 5, the impact is taken as 50 per cent and 100 per cent.

Will the author please say why the curves were not drawn with higher values of impact ?

On page 4 the author states that reasonable control of speed of motor vehicles is necessary in the interest of the road as well as for safety of passengers, pedestrians and other road-users. Even agreeing that control of speed is necessary, the main factor to be considered is how to control the speed in a practical way. To my mind no *practical* way of controlling the speed can be devised. If my professional brothers agree with me, then the only solution will be to design and construct roads for speed. The question of cost will then be raised by the learned authors. Well my answer is that Motor Transport contributes more than enough money by way of different taxes. Why not spend that money on roads and invite more vehicles on the road and thus increase revenue. I have obtained certain figures[1] from the General Secretary, Indian Roads and Transport Development Association showing expenditure on (a) P. W. D. and Local Board Roads, (b) Municipal Roads and (c) Roads in Indian States and also particulars of revenue derived from Motor Transport which I am sure will be of interest to members.

The impressions of high pressure pneumatic tyres given in figures 1-3 show that with the increase in wheel load on the same tyre from 2,200 pounds to 3,300 pounds and 4,400 pounds the pressure on the road surface increases from 93 pounds per square inch to 98 pounds per square inch and 100 pounds per square inch. Does this mean that by increase of laden weight of a vehicle the effect per unit area on road surface is not so great with pneumatic tyres ?

The author gives very useful information in the table on page 10 regarding loads per inch width of bullock-cart iron tyres but Bombay Presidency is omitted. If the figures relating to this Presidency are given it would make the information more complete. From the table it will be seen that barring Assam the maximum load per inch width of tyre varies from 410 to 1,800 pounds. As the iron tyre is not elastic, could this load be taken as so much per square inch and if so the load on surface with pneumatic tyres as seen from figures 1-3 works out to only 93 to 102 pounds per square inch, i.e., only 1/18 as compared with bullock-cart iron tyres. Knowing this, is it not advisable to advise the Government of India to encourage bullock-cartwalas to change over to pneumatic tyres by exempting them from all road taxes or even by paying them some sort of subsidy ?

Mr. T. R. S. Kynnersley (Bombay) : On page 11 there are certain interesting remarks in the last paragraph. The paper says :—

" So far as the pneumatic-tyre motor vehicle is concerned, for ' flexible' type of roads built over alluvial soil as commonly occurs in the plains of India, it is necessary that the crust should be 10 inches thick if wheel loads of 2 tons are permitted."

Where on earth are you going to get the money ! In designing a road we have to remember that the damage is not done by the motor car

[1] These figures were subsequently supplied by Mr. Nadir Shah and will be found in statements Nos. I-IV under the heading " Correspondence."

alone, we have to take into account bullock-carts and the weather. In India we have all types of weather, drenching rains followed by scorching sun and practically every condition calculated to destroy roads. The greater the unevenness of road the greater the impact caused by revolving wheels.

Mr. M. S. Duraiswamy Ayyangar (Travancore): Most of our roads are earthern roads and are fair weather roads fit for motor bus and lorry traffic in good weather only, but not safe for even one motor vehicle in winter. Bullock-carts, however, use the road with or without difficulty in all weathers. People have now taken up to motor traffic and for suburban traffic motor vehicles are necessary and they cannot be stopped totally without inconvenience to traffic. We know frequency of load wears down our roads rapidly. It is therefore desirable to limit the number of trips allowable with safety to keep up suburban traffic as long as practicable. Ordinarily in these roads, vehicles can take about 2 tons total load. It is therefore desirable to classify roads according to the maximum capacities which lorries can take and buses can carry.

Mr. R. A. Fitzherbert (Bombay): A member has suggested that all bullock-carts should be fitted with pneumatic tyres.

Now there are several ways in which we can counteract or reduce the damage done to roads by bullock-carts

(*a*) We can find money to pay for this damage by taxing the bullock cart, but this does not now seem possible.

(*b*) We can have all bullock-carts fitted with pneumatic tyres as already suggested. Now at a rough estimate there are probably over half a million bullock-carts in the Bombay Presidency. and as the cost of a pair of tyres is somewhere in the neighbourhood of Rs. 120 the total outlay involved would be heavy, and this would have to be met by Government

or

(*c*) We can have all bullock-carts fitted with wooden wheels 4 inches in width. but this again means a heavy outlay by Government, as a pair of wheels would cost probably Rs. 50.

Mr. A. Lakshminarayana Rao (Masulipatam): I wish to bring to the notice of the authors of this paper one point which they have, probably, inadvertantly missed to mention in their paper. which is exhaustive in all other aspects. The relation of load and speed to tractive resistance offered by the road has not been discussed in the paper. I have made some humble experiments in this field and I found that when a 2-ton-bus travels on a road with a speed of about 25 miles an hour. the tensile stress exerted on the road crust will be about 40 to 60 pounds. I have not been able to complete the investigation and so I cannot place before the Congress complete results. Again, I made certain other experiments with regard to tensile strength of gravel and it was found that the tensile strength of most of the gravel that we use is barely ½ pound per square inch. Is it possible under the circumstances to increase the loads on such roads without designing a better crust and will it be possible for our roads to resist greater load and greater velocity without improvements to surface? Obviously a 4½-ton vehicle running at 30 to 40 miles speed will necessarily create a greater tractive resistance on the crust of the road and to design such a road will be extremely difficult. It is within our experience that a bit of road between Bezwada and Nandigama, which was in an excellent condition went to dogs within one year owing to the introduction of heavy lorry traffic on this road.

One more point. By increasing the permissible load and velocity, whom are we benefitting? Let us understand that we are Indians first and then Indian road engineers. The double bullock-cart is a source of subsidiary occupation for the ryot. During the off-season he takes the produce in the double bullock-cart and earns a few more rupees. Is it in the economic interest of our own country to drive away double bullock-carts? I believe you will all agree with me that it is not desirable. In the interests of our roads, we have to induce them to use pneumatic tyres.

One speaker wanted that we must build our roads to stand more speed. Already we hear of so many deaths due to accidents on account of the high speed of motor cars. Shall we, engineers, be the cause of more deaths in our country? I feel that it is very desirable to limit the speed of motor vehicles.

Another member observed that the money derived from motors is not fully spent on the roads. but that a portion of it goes to the general revenues. I beg to state that this statement may not be correct. In the Madras Presidency, at any rate, the Government is spending the income derived from roads on the road itself and a little more from the general revenue.

Nawab Ahsan Yar Jung Bahadur (Hyderabad Deccan): The Madras Government is a very good Government.

Mr. Jagdish Prasad (Author): At the outset I would point out that our paper particularly refers to the carrying capacity of the existing roads. Mr. Raj Mohan Nath has said that the width of the bullock-cart tyre we suggested in the paper was rather too much. The width depends upon the intensity of pressure that can be transmitted on the road surface without detriment to it. I personally think that for a steel-tyred bullock-cart, tyre width of less than 4 inches will be detrimental to painted surface unless wheel loads are reduced. Mr. Das Gupta questioned the statement that twin tyres produced greater impact than single tyre under similar load, speed and road conditions. The statement is correct and has been explained in the paper. Mr. Radice has already explained that impact on bridges should not be confused with wheel impact on roads and I need not repeat what Mr. Radice has just said. I may inform Mr. Das Gupta that the question of Rail-Road Competition does not enter into this paper which is meant to throw light on what the existing roads can carry. In a country which is already inadequately supplied with metalled roads our problem at present is to attempt to increase that mileage and to preserve the existing roads. I am glad that Rai Sahib Fateh Chand agrees with the suggestion made in the paper regarding restriction of speeds and loads. I agree with Mr. Bhatt that the size of the grain affects the properties of the soil. I may point out that as in a particular locality the supporting power of the soil varies according to depth of foundation and changes several times in the year, as there is greater fluctuation in road foundation soils than in the deep foundations of buildings, and as in the former case the sub-soil is more exposed to the effects of weather and to the so-called "churning action" of varying moving loads, it is not practicable to be very accurate about the bearing capacity of a particular sub-grade and to apply laboratory methods for its determination. I agree that the possibilities and economies of improving sub-grade capacity should be investigated but so long as the thin iron-tyred bullock-cart exists we will have to provide sufficient crust of metal through which the load of the bullock-cart wheel can be distributed.

I am glad that Mr. Murrell is in general agreement with the paper. I have not read the paper by Mr. Ravenor referred to by Mr. Murrell but I do not think that it is reasonable to presume that ordinary alluvial and sandy soils behave like pure moist clay and could bear greater pressure under moving loads. I may also point out that I have considered the wheel load as uniformly distributed over the sub-grade to simplify calculations. Actually a pressure, greater than the average intensity of load occurs directly under the wheel. The Massachusetts Commission of 1901 determined the values of well compacted and well drained sub-grade soils and they came to the conclusion that 25 pounds per square inch may be allowed for coarse sand and gravel and 4 pounds per square inch for the poorer clays and very fine sands. For these reasons and as already explained in the paper, I do not think it is desirable to give greater bearing values to the various indigenous soils than those given in the paper.

Mr. Nadir Shah wants to know why depth of macadam curves for higher impacts have not been given in the paper. We have assumed that the impact on a rough road is about 100 per cent. According to tests carried out in England and America, the maximum blow is about 2¼ times the wheel load. I may inform Mr. Nadir Shah that speed can be effectively governed by means of speed governors and it appears desirable that these should be fitted to all buses and lorries.

Mr. Nageswara Ayyar has referred to the bye-laws in the Madras Presidency restricting the load of motor lorries to 3 tons gross load. That is probably going very much further than what the authors have contemplated in the paper. If roads in any particular area are not safe for 2-ton wheel load and there are no funds to reconstruct them, we have no alternative but to fix a lower limit for permissible wheel loads.

Colonel G. E. Sopwith (Chairman): Before thanking the authors and those who have contributed to the discussion I should like to refer to one point. On page 11(e) the authors state "For all practical purposes the bullock wheel load may be assumed as a concentrated point load, the distribution of pressure through the road crust as conical and the area of the sub-grade over which the pressure is applied as a circle of radius equal to the thickness of the road crust." On this basis they calculate that a thickness of 9¼ inches of road metal is required to carry a wheel load of 1 ton on roads through black cotton soil and of 1½ tons when the road is built over alluvial earth and loam.

A large number of experiments were carried out in Peshawar to ascertain the area of wheel or iron tyre in contact with the road surface at any given moment and an average area of 1¼ square inches was the result. The area of pressure on the sub-grade is therefore approximately a square with sides of thickness of crust plus 1½ inches and thickness of crust plus 1 inch respectively. For a 3-inch thickness of crust the area of pressure is 80 per cent greater than that calculated by the authors and for a 6-inch crust 56 per cent greater. It is clear that the diagram so far as bullock-carts are concerned gives thicknesses much greater than are necessary. This paper which was extremely interesting has led to a discussion which was even more interesting than the paper itsel.. Mr. Jagdish Prasad has stated that the paper has been written for the roads as they exist. In my opinion, that is not going far enough. I agree with the other speakers who have said that we should concentrate on soil sub-grades in order to be able to take more loads.

On your behalf I thank Messrs. Mitchell and Jagdish Prasad and those who have contributed to the very interesting discussion which we have had.

Mr. S. G. Stubbs (President): I propose a vote of thanks to Colonel Sopwith—(*acclamation*).

CORRESPONDENCE

The information contained in the following four statements is referred to in Mr. Nadir Shah's speech on page 27(e) and was supplied by him subsequently.

I. Revenue from Motor Vehicles.

(1934-1935).

		Rs. lakhs.
Import duties on motor vehicles and parts thereof	...	133·69
„ „ on pneumatic rubber tyres and tubes	...	34·89
„ „ on motor spirit	...	5·18
Excise Duty on motor spirit	...	490·18
Provincial, Local and Municipal Taxation, approximate.	.	275·00
		Rs. 938·94 lakhs

N.B.—The Excise Duty on petrol is increasing every year, at the rate, roughly of 10 per cent.

II. Expenditure in British India on P. W. D. and Local Board Roads during the year ending 31st March, 1935.

(From Provincial and Local Revenue)

Province.	Original works. Rs. lakhs.	Repairs. Rs. lakhs	*Total.* Rs. lakhs.
Madras	. 36·5	99 8	136·3
Bombay	... 15·0	42·4	57 1
Bengal	.. 2·2	21·4	26 6
U. P.	... 0·7	30·4	31·1
Punjab	... 2·8	59·1	61·9
Bihar and Orissa	... 7·4	12·1	49·5
C. P.	... 3·9	31·1	35·0
Assam	... 1·6	27.5	29·1
N. W. F. P.	.. 0·5	18·7	19·2
Burma	... 3·7	36 7	40·4
	74 3	412·2	486·5

Add: Probable expenditure on Original Works from the Central Road Development Fund, estimated 80·0

Total expenditure on P.W.D. and Local Board Roads .. . .. 566·5 lakhs

III. Road Expenditure on Roads in Charge of Municipalities in India during the year 1934-35.

(Excluding the cities of Calcutta and Madras.)

		Rs. lakhs
United Provinces		12·17
Bombay and Sind (excluding Bombay city and Karachi)	...	15·41
Bombay City.	...	54·80
Karachi	...	3·14
Bihar and Orissa	...	4·66
Bengal excluding Calcutta	...	8·66
Assam	...	1·77
Punjab	...	9·06*
Madras excluding Madras City	...	16·98
Central Provinces	...	3·83
N. W. F. Province	...	0·78
Burma	...	9·91
		Rs. 141·17 lakhs.

Approximate expenditure inclusive of Madras and Calcutta, say, Rs 200 lakhs.

IV. Expenditure on Roads in Indian States during the year 1934-35.

		Rs. lakhs. Original Works	Repairs.
Hyderabad State.	...	19·60	20·95
Mysore ,,	...	1·31	11·41
Travancore ,,	...	6·66	9·08
Cochin ,,	...	2·08	2·17
Indore ,,	...	0·99	2·74
Jodhpur ,,	...	0·55	1·62
Bahawalpur ,,	...	0·65	0·93
Baroda ,,	...	2·59	2·69
Gwalior ,,	...	0·89	9·25
		35·32	60·84

Total :

Originl Works and Repairs Rs. 96·16 lakhs.

Probable total expenditure including other States. 125 lakhs.

* Does not include expenditure on Road watering amounting to Rs. 2 lakhs.

Paper G.

Chairman—Mr. W. L. Murrell (Bihar):

In the absence of Mr. G. B. E. Truscott (Author) the following paper was taken as read :—

PAPER No. (G)

CORRUGATIONS ON ROAD SURFACES.

By

G. B. E. Truscott, Chief Engineer, Travancore State.

There was some discussion during the third session of the Congress regarding corrugations in roads and the drawings attached to this paper show corrugations on two roads with which I am familiar and are offered to the Congress in the hope of raising a discussion as to the best methods of dealing with corrugations generally.

When building gravelled roads nowadays, we build a girder section (*vide* Fig. 1) of about 18 inches deep by 2 feet wide and 4 feet 8 inches centres to carry traffic, which does not give much trouble by corrugations forming on the surface, but the two roads referred to were not so constructed and were purposely measured as they indicate what is likly to happen to metalled roads in course of time. The foundation of road (*i*) (*vide* Fig. 2), is sand and the formation is of 6 inches of laterite with about 8 inches of gravelled surface. The foundation of road (*ii*) (*vide* Fig 3), is of hard soil with 6 inches to 9 inches of gravel formation. These roads have not given much trouble in the past, but with the advent of fast moving motor traffic, corrugations as shown in the drawings form within about six months. It will be noticed that the corrugations generally vary from about 22 inches to about 30 inches and are fairly regular. It may be mentioned that the surfaces are consolidated with hand or petrol rollers of 4 to 5 tons in weight and it is likely that the reason may be attributed to light consolidation. But I have noticed the same in a lesser degree occur on metalled roads formed of hard metal and consolidated with a heavy roller and also some which have been surface treated. It may be that the cause is by the friction of the wheels of fast moving motors slightly moving the whole metalling from its foundation or by the impact of the wheels crushing the under-surface and destroying its bond with the soling or foundation and so allowing the metalling to be rucked up like a carpet ; but I do not propose to advance any theory, but give the information in the hope of obtaining the views of the members as to the best way of dealing with such problems. Concrete specialists will probably suggest that the solution will be to lay concrete roads ; but the time is far distant when such a happy ending is likely and water-bound metalled roads with or without surface treatment are going to be with us for many years to come and we have to make the best use of the materials at our disposal as with the advent of rubber-tyred bullock-carts, the surface of roads will not in future be cut up as much as now with the existing iron-tyred wheels, and surfaces will last for a longer time, and road engineers will not be so keen to dig up and reform what is otherwise a good surface merely because it is corrugated, especially if it has been surface dressed. This is a short paper but I hope I have given sufficient data to provoke a long and extended discussion.

GIRDER SECTION OF GRAVEL ROAD.

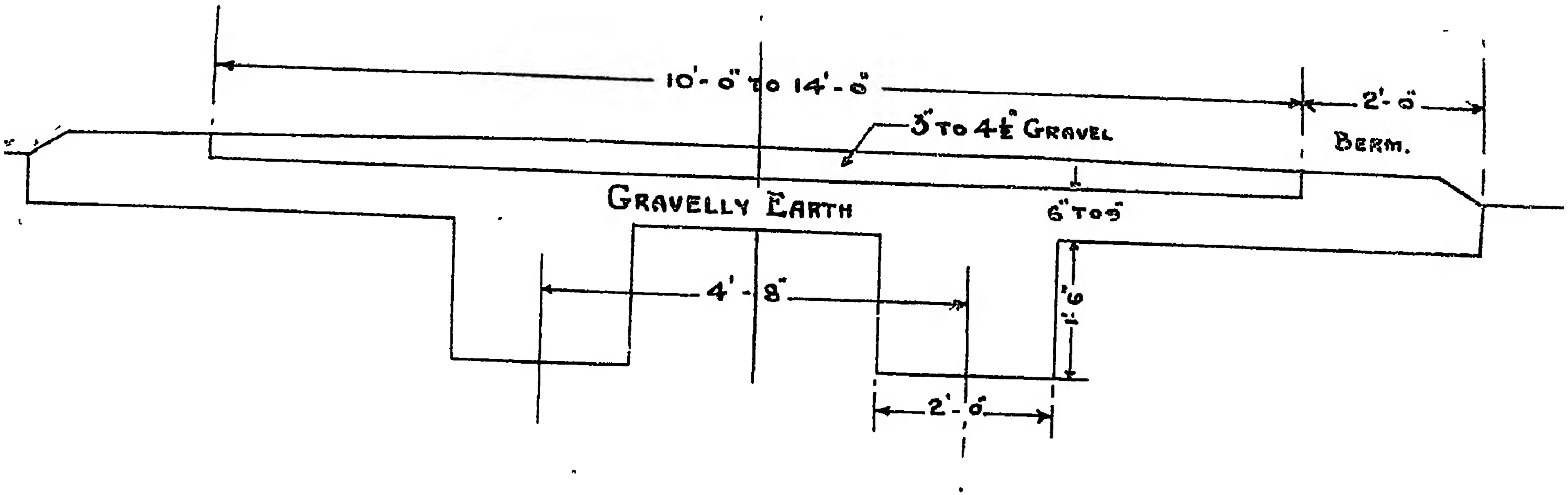


FIG. 1.

Disscussions on Paper No. G.

Mr. W. L. Murrell (Chairman) : This last of a series of very interesting papers of the Fourth Indian Roads Congress introduces a subject that is of vital importance to all road engineers in India who have insufficient funds at their disposal to enable them to cope with the ever-increasing motor traffic. Mr. Truscott has performed no mean public service in giving us his paper, and it is unfortunate that he could not be present to see the results of his initiative. We miss his genial personality. Mr. Truscott expects a long and extended discussion, so I propose to have "first say."

I do not quite agree that the author's use of the word "weight" as applied to road rollers, is quite correct. Should we not use the word "size"?

It is very doubtful whether a 12-ton roller will give a greater intensity of pressure than will a 6-ton roller. The great point is, I think, that the larger roller can do almost twice the area in a given time.

And now, for road corrugation. I would quote portion of an article which was published in *Indian Engineering* for October 7, 1933. It describes a simple experiment on a motor vehicle, and indicates a very probable cause of corrugation : "Jack up one rear wheel of a motor car. Keep the other rear wheel on the ground and between chocks. Put the car into gear and release the brakes. Next, grasp the lowest part of the lifted wheel and move or rotate it a little forward, i.e., towards the front wheel, until the resistance of the engine compression can be felt.

A little consideration will show that under these conditions, with the hand pushing the lowest part of the tyre forward till the compression is felt, every single pair of rolling or sliding friction surfaces in the whole of the power and transmission systems—from the piston right down to the rim of the grasped wheel—is arranged exactly as if the gas expanding in the cylinder were being employed to make the rim and tyre push the road backward relatively to the car : that is to say, as if the car were being driven ordinarily along the road.

Now get two or three persons to stand on each running board and bounce the body of the car up and down as though it were travelling on a roughish road. It will be found that every time the car body comes down on the springs, the portion of the wheel grasped and thrust forward by the observer, gives a definite kick backward. This phenomenon is even more obvious if the rear snubbers, or shock absorbers, be removed. In other words, when a car is moving along a road, for every bump the road gives to the back wheels, they retaliate on the road immediately with a vigorous kick."

And, obviously, the higher the speed and the greater the pressure in the cylinder—the more severely will the bump be felt, and the more severe will be the backward kick of the wheel.

Still further, so long as the car continues to bounce after such a bump, so long will it continue to administer a series of such kicks. It seems to me that these backward kicks are the chief cause of corrugation,

To see is to believe. I invite you to inspect the car which has been jacked up outside. Needless to say, the phenomenon is common to all motor vehicles, regardless of type or make.

There appears indeed, a complete analogy between this phenomenon and the formation of waves at sea, which are increased by the force of the gale striking their summits.

At sea also the deeper the water, the larger can a wave become. On a road, where there are softer conditions in the sub-grade, the larger can a corrugation become.

That, gentlemen, is the theory of road corrugation, which I submit to you.

As to the prevention of corrugation, I know of no method, but something can be done to minimise it.

A few months ago, Captain Hall, C.I.E., M.C., the Chief Engineer, Bihar, presented Rs. 50 as an honorarium to sectional and sub-divisional officers for the best paper on the prevention of water-bound road corrugation, (*a*) presuming that sealing was not financially possible, and (*b*) assuming that it was.

Of course, gravelled and even built-up earthern roads will corrugate, but in Bihar the Public Works Department are concerned more with water-bound macadam

There was an enthusiastic response from the out-door staff. It is interesting to note that the replies showed the supreme importance of getting a good smooth surface, as free from bumps as possible, at the time of consolidation of the water-bound surface.

To effect this the sub-divisional officers laid stress on several practical requirements, some of which are :—

(1) To obtain evenness of grade by checking the consolidation longitudinally with a 50 feet string during dry rolling.

(2) To prevent local depressions during dry rolling by loosening the partly-consolidated metal in low spots, and sprinkling a few handfulls of more metal before continuing the dry rolling.

(3) To prevent the formation of initial waves during consolidation by having the roller-gearing in good condition, so as to prevent jerky rolling, and by taking long runs so as to minimise stopping and reversing the roller.

But, above all, the sectional and sub-divisional officers stated that by far the easiest way of minimising corrugation was to seal the water-bound macadam.

It might be mentioned that a few months before the receipt of these papers, I had offered an honorarium for the best paper on the sealing of water-bound macadam. The results were instructive and led to changes in specification. In addition, all concerned showed a greatly increased keenness on their out door work.

Indeed, the Government of Bihar have now allotted Rs. 200 annually for such honoraria, and it is hoped that we will be able to do more to combat corrugation and other road troubles in the future.

However, the Chairman has wandered off the subject, and it is hoped that this grave offence will not be committed by the speakers who are now invited to express their opinions from this platform.

Mr. Iftikhar-ud-Din Mufti (M. E. S.): Corrugation, or waves, or undulations liable to appear in all types of roads surfaces are often due to

(*a*) Improper consolidation.
(*b*) Use of unsuitable binders.
(*c*) Uneven sub-grade.
(*d*) Inadequate key with the soling of the road metal.
(*e*) Inadequate grasp of the nature and permeability of soil on which the roads were originally made.
(*f*) Lack of proper drainage in the sub-grade.

No matter how durable road metal and gravel may be, they cannot be used successfully in a road surface unless they can be well bounded together to offer a successful resistance to moving and variable traffic.

Clay is the usual binder available The suitability of any particular clay for use as a binder depends upon its properties. If a good (non-slaking) variety of clay is not available, the clay must be mixed in suitable proportion with sand. Even with light traffic many failures were found, these were not due so much to the wrong use of metal or gravel but to the fact that very little attention had previously been paid to the proper preparation of the sub-grade of the original road. The chief enemy of the road, however, is a damp foundation. This dampness penetrates through the surface either by condensation or by water working in from the sides of the road. Further, if the sub-grade is weak it will deform due to the ponding action traffic, because the surface is not strong enough. A cure of this might be to put down such a strong key with the soling of the metal that it will itself support the weight and sustain the thrust of the traffic. It must be realized that it is the sub-grade which really carries the weight of vehicles and that the formation of the road is merely to distribute that weight over a larger area. The sub-grade must be prevented from moving to such a degree as will cause deformation of the road surface above it, under the action of traffic. If the sub-grade is composed of unsuitable material and if water has access to it. the earth underneath will move and the road surface will form corrugations. It will be seen that the character of the sub-grade has a great effect upon the stability of the road surface no matter what material may be used for the latter. Unless the foundation is hard and firm and properly shaped. the resulting road will be bad and will remain bad. Improperly made sub-grades are the causes of great waste of money and frequently when a road breaks up, the blame is placed upon the particular type of binder used, whereas the real cause was probably a badly prepared sub-grade.

Many failures in road construction works are due to the lack of proper drainage of the sub-grade. It has generally been the case that owing to paucity of funds for construction, savings have been made by omitting culverts, etc., or in other words, by taking a chance in the matter of proper drainage. Money can he saved in maintaining the roads and thereby increasing their life if improvements on the drainage of roads are carried out systematically and thoroughly. In this respect detailed reconnaissances should be made under flood condition to find out exactly how and where drainage is deficient. The principle of drainage should be that surface water is taken away from the road and road-sides before it has time to saturate in the sub-grade from the side drains.

Mr. G. D. Daftari (Bombay): Corrugation seems inevitable on roads having water-bound surfaces, carrying fairly heavy and fast-moving traffic of mechanically propelled vehicles. I am not aware of any method by which they can be entirely eliminated, though methods have been devised to delay their formation to some extent.

Motor vehicles, fitted with springs and pneumatic tyres and moving with speeds varying from twenty to forty miles per hour, by their very nature, exert "pulsating" pressure on road surfaces as distinguished from uniform pressure. Such pulsating pressure, combined with roughness of surface, results in producing hammering-action, which helps formation of corrugations on water-bound surfaces sooner or later.

One way to delay their formation is to allow a period of a couple of days, after consolidation, before opening the road to traffic, It is observed

that if traffic is allowed over freshly prepared surface without allowing time for the surface to harden, corrugations form within two weeks, while if a couple of days' interval is allowed the formation of corrugation is delayed for about three months.

In the Poona Division, we have some 300 miles of water-bound roads. We engage maintenance coolies, at the rate of a mile a cooly or two miles a cooly, according to the importance of the road. One of the duties of the mile-coolies is to fight the corrugation. The fight consists in disturbing the corrugations in blindage by brooming the surface fairly frequently. It is estimated that about one-third of the time of these coolies is spent in such a fight, and the annual cost per mile is roughly computed at Rs. 20 per year. Thus, an amount of about Rs. 5,000 to Rs. 6,000 per year is spent in a Division like Poona in fighting this evil of corrugations, and I shall be very grateful if some members of the Congress will tell us, or can suggest, what steps they are taking to meet with the evil.

Mr. U. J. Bhatt (Bhavnagar) : This is indeed a thought-provoking paper. The first thing one notices in the chart is the regularity of the corrugations. This regularity suggests that corrugations have a definite relation to speed, which ranges between 15 and 50 miles per hour in urban roads and with the diameter of the wheels. I agree with Mr. Daftari that the corrugations are due more to pulsating pressure. The members of this Congress would have noticed the regular corrugation on the road between Hyderabad and Secunderabad. I was given to understand by the engineer in charge of this road that this corrugation was only temporary and that it would be prevented from further growth by surface coating. But as soon as the new coating loses its elasticity the corrugations will re-appear. It is the advantage of cement concrete that as it has a hard face it will prevent corrugations forming easily.

Mr. J. C. Guha (Bengal): Wave formations are noticeable on almost every kind of road surface subjected to heavy and fast-moving motor traffic, possible exceptions being stone-sett pavement on concrete foundation and cement concrete paving. The latter types of roads are left out of consideration as these are very expensive and as the author of the paper rightly observes, in the case of cement concrete roads that the time is far distant when such happy ending is likely and water-bound metalled roads with or without surface treatment are going to be with us for many years to come. We shall consider the cases of water-bound metalled roads only with or without surface treatment.

Broadly speaking, corrugation on road surfaces are due to the following causes :—

(1) Tractive resistance. The tendency to corrugate varies directly as the tractive resistance. The lower the tractive resistance, the less chance is there of waviness being set up.

(2) Vibration at the rear wheels due to sudden increase in the driving force to overcome the front wheel resistance. This vibration causes periodic wear at the driving wheels and consequent waves.

(3) Tangental force due to driving action. This has the effect of moving the fine materials towards the ridges of the waves.

(4) Frictional force due to breaking, which helps the wheel action to make the road materials creep forward.

(5) Vacuum or sucking effect at the back of the moving wheels of motor cars. This loosens the blinding materials, facilitating formation of corrugation and pot-holes.

Let us first take the case of water-bound metalled roads without surfacing. In this case, the factors mentioned before together with the impact of the moving wheels and weather action cause disintegration, movement of the surface and formation of waves. In the past, bullock-carts and other traffic would cause disintegration of road surfaces and pot-holes, but there was no trouble with corrugations which are mainly the result of fast-moving motor traffic. The corrugation being fairly regular as observed by the author of the paper, may be due to running of several vehicles of the same type and same length of wheel base on these roads. There might be other reasons for this which require investigation.

We next consider the case of water-bound roads painted with tar or bitumen.

Formation of waves is of frequent occurrence in these roads. This is brought about by the fine topping course moving backwards and forwards into waves while the larger materials remaining in the hollows.

To mitigate the causes of corrugations in painted roads, I tried the following method with fair success in Bengal.

(1) Minimum but adequate quantities of matrix in view of the condition of the water-bound surface were found satisfactory. Quantities in excess were found to favour formation of waves.

(2) In surface painting, fine stone chips or sand caused corrugation. Stone chips 3/8-inch to 3/4-inch size containing a large proportion of ½-inch, gave very good results.

(3) Two coats of surface painting were put initially, the second coat being put two to three months after the application of the first coat. The base coat was of thin road tar or thin liquid asphalt of high penetration power, but the second coat was of hot bitumen. In one experiment over laterite surface, a top coat of hot bitumen painting over a base coat of liquid asphalt gave satisfactory results.

Another usual method of surface treatment is bituminous grouting of 2-inch thickness. This is more expensive than painting, but is applied on roads subject to comparatively heavy traffic. Corrugations are noticed in these roads also. In this case too, satisfactory results were observed by the use of minimum quantities of matrix and large stone chips. Premix carpeting gave better results than grouting. The reasons are obvious. I used 2 inches of shelcrete over 3 miles of a road, 12 feet wide, more than a year ago. The foundation consists of 2 inches to 3 inches of Rajmahal stone metal, over 6 inches of Jhama metal and soling. This road is subjected to very heavy motor traffic. Excellent results have been obtained so far, and there are no signs of corrugation. The cost compared favourably with other kinds of grouting or carpeting, which were experimented on the same road. The firm charged hire for the mixing plant and pay of the driver at Rs. 16 for each working day and Rs. 8 for each non-working day. If they could reduce this charge, the cost would be still less.

It may be rather easy to reduce the chances of corrugation by taking precautions when new surfacing is done. The question is how to remedy the waviness that has already occurred on bituminous roads. This is a problem which requires investigation to find out the best method of dealing with it.

Mr. R. A. Fitzherbert (Bombay): The author suggests that corrugation is caused "by the friction of the wheels of fast-moving motors slightly moving the whole metalling from its foundation or by the impact of the wheels crushing the under-surface and destroying its bond with

the soling or foundation and so allowing the metalling to be rucked up like a carpet." In my opinion, corrugations may be caused by the vertical oscillation set up by the springs and the resultant varying pressure of the wheels on the road. Probably the wheels periodically spin or skid, exerting a brushing effect along the axis of the road.

With reference to corrugations appearing in blindage, such corrugations unless remedied immediately are eventually transmitted to the metal surface; I have seen them on a new road surface. My experience is that roads made with soft road metal corrugate much more quickly than roads made with hard road metal. Some engineers say that sand blindage corrugates more readily than moorum blindage, but the experience in other Provinces such as Bihar is quite different. I have noticed corrugations even on earth roads used only by bullock-carts. This sounds incredible, I know, but there were definite short ridges on the earth roads used by bullock-carts which were definitely corrugations. Sometimes we get a wavy surface on roads immediately after consolidation and this can only be explained by assuming that the road-roller pushes the metal along, making a ridge, and then rolls over this ridge.

Mr. W. A. Radice (Calcutta): It has been very interesting to me to hear the views of so many delegates on the probable causes of road corrugations. I am not a road engineer but I think I may perhaps save a considerable amount of speculation if I tell you something of the investigations which have gone on for years into the causes of rail corrugations generally known as "roaring rails". It may comfort road engineers to know that railway engineers, after years of study, still consider the problem as insoluble. As, perhaps, has been revealed by today's discussion this is a subject about which *quot hominos, tot sententiae*.

In spite of a diversity of opinion there are certain results which seem to me to be valuable pointers towards finding a solution of the road corrugation problem.

As several speakers have indicated, the first factor that naturally comes to one's mind is the road surface. In the case of "roaring rails" the surface is rolled steel and infinitely harder than any road surfacing material. In spite of this hardness, under certain circumstances, regular corrugations form on their surface, exactly as on our courderoy roads, except that the pitch of the corrugations is much smaller, of the order of 1 to 2 inches and the depth much shallower. This fact seems to indicate that the nature of the road surface is not a factor causing or not causing corrugations and my deduction from the railway analogy is that it would be waste of time to pursue the investigation further in this direction. There can be no doubt that the nature of the road surface has an influence on the registration of the effect; for instance a plastic road surface will register corrugations more easily and more pronouncedly than a harder road surface, but this responsiveness of the road surface must not be confused with the inherent causes producing these objectionable corrugations.

The railway engineers also followed this line of thought and the rail corrugations were ascribed by some to the process of rolling the steel into the rail shapes. It was thought the corrugations being regular, that in rolling, the metal was squeezed up in waves of hardness. This rather speculative idea has been definitely disproved by trying out in places where rails persistently became roaring rails, rails rolled in different ways, slowly and faster, at differing temperatures and for varying periods with varying number of passes through the rolls. In the outcome it was

found that none of these variations had any effect on the appearance of corrugations.

This negative result pointed the way to another possible cause, that is the stability of the road bed. It was found that certain stretches of line always produced roaring rails and that others did not. Systematic comparison of observations soon established the fact that the stretches of line where corrugations formed were generally on quaky or vibrating soils.

An example of historical interest is perhaps worth quoting. When Stevenson began building the first railways, one of the earliest was the line between Manchester and Liverpool. The railway engineers were faced, in this construction, with the problem of building a high embankment across Chats' Moss, a swamp in which whole oxen were reputed to have disappeared. All attempts to cross this bog were unsuccessful until the idea occurred to Stevenson to float the embankment, A large mattress of brushwood, over 20 feet thick was deposited across the marsh and the earthwork was made on it. As earth was deposited its weight drove the brushwood mattress into the bog until the embankment rose to the required height where stability was reached. The success of this device can be appreciated by the fact that this embankment carries to this day some of the fastest expresses in the world in perfect safety. It is, however, one of the worst stretches of line for the formation of roaring rails.

Other well-known stretches are the first few miles of the East Indian Railway main line out of Howrah, and the Dacca-Narayangunj section of the Eastern Bengal Railway. In another bad case a cure was effected by using sleepers 18 feet long instead of the standard 9 feet 6 inches.

I would suggest therefore, that the cause of corrugations may be the vibrational properties of the road embankments and of the soil on which they rest and would suggest that the line of enquiry most capable of bearing fruit would be a careful classification of all stretches of roads where corrugations occur and a comparative study of the natural period of vertical vibration of the embankment and subsoil and of the amplitude of the vertical vibrations produced by dropping on the road a standard weight from a standard height.

When we consider that vehicles passing over a road do so at differing speed, that the axle loads and the springing vary, even the tyres vary, it seems conclusive that it would be difficult to find the inherent cause of corrugations in the vehicles themselves or the action of their wheels on the road surface in view of the regularity of the corrugations themselves as clearly brought out by Mr. Truscott in his paper. The role the vehicles play in the matter would appear to be limited to the causing of vertical vibrations in the roadway as we have all experienced when a heavy lorry passes in the street outside our residence or office.

To the objection that all road beds are necessarily vibratory and that therefore all roads should corrugate. my reply would be that in dealing with manifestations due to small vibratory effects the determining factor is resonance. We have all heard of the perfectly true statement that if we could eliminate internal friction a series of drops of water falling regularly on a bridge girder at the precise interval of the natural period of vibration of the girder would set it vibrating with ever increasing amplitude until the girder would shake itself to pieces.

If systematic investigation on the lines suggested by me should reveal that vibrational resonance is the true cause of road corrugations, the

discovery would simultaneously give us the means of curing the objectionable tendency.

In the case of a vibrating mass such as a road embankment and the soil on which it rests the natural frequency of vertical vibration varies directly as the square root of the coefficient of sinkage of the mass into the soil under the effect of the vibration. In order to avoid resonance either the mass vibrating should be varied in weight or size or the value of the coefficient of sinkage changed or both.

This could be effected in several ways, such as driving a few piles through the mass, introducing a soling of stones under the macadam surface or even by altering the specific gravity of the road metal, etc. etc.

Mr. Fitzherbert's experiences which he has just given us seem to confirm this.

Thus my advice is to locate systematically the stretches of road which corrugate persistently and to study the vertical vibrations produced therein by a standard impact. Everything seems to indicate that a comparative study of the results may lead to important conclusions and show the way to remedy the trouble.

Mr. N. Das Gupta (Calcutta): The problem of corrugation of roads is a most complicated one and the causes of corrugation are different for different types of roads, i.e., whether it is water-bound macadam, gravel, or bituminised road. I would give my humble views on the subject before the Congress for its consideration.

The corrugations in the water-bound surface are mainly due to insufficient metal and bad rolling. Very rapid rolling with a bad jerky roller is sure to produce marked corrugations in a water-bound road even if the stone may be of the best available quality.

The corrugations in gravel, I believe, are due to want of proper grading of the soil. If a sieve test of the gravelly soil be made and the deficiency in any particular size be made good, so that the mix may adhere to the maximum density curve, as far as practicable, there will not be any corrugations.

The corrugations in the third case, that is in bituminised roads, are due to excess of bitumen, if the base on which the carpet has been laid was true to grade and camber.

The method of stabilising gravel roads in order that they may not corrugate would be to analyse several samples of soil taken from different parts of the road to be improved, and find out the percentages passing through standard sieves of 10, 40, 80 and 200 mesh. A maximum density curve will give the percentage of materials passing through each sieve that will be required to make a mixture, which would theoretically contain no voids. The next step would be to add the materials which are deficient in the samples tested. By several tests it will be possible to find out a composition which would give a curve nearly identical with the maximum density curve.

Satisfactory general grading limitations are as follows:

Passing 1-inch screen	...	100 per cent
Total passing ¼-inch screen	...	50 to 70 per cent
,, ,, 10 mesh sieve	...	35 to 60 per cent
Passing 200 mesh sieve	...	7 to 14 per cent

As a protection against the ravaging effects of heavy showers of rain, this stable mixture can be treated with a light slow curing cut-back asphalt according to the empirical formula:

$$P = {\cdot}02\,a + {\cdot}04\,b + 0{\cdot}2\,c$$

where P = percentage of cut-back asphalt required
a = percentage of materials retained on a 10 mesh sieve, gravel or shingle.
b = percentage of material passing 10 and retained on 200 mesh, i.e., sand.
c = percentage of material passing 200 mesh, i.e., dust.

Mr. S. R. Panje (Anantapur) : The reasons advanced in the paper seem to me to be the causes in the main, unless or until the contrary is proved. I would only try to amplify these slightly and seek enlightenment at your hands on these points. If these details are true, the remedies are also plain.

When a roller is in action, the metal immediately in front of its bottom point moves slightly forwards and downwards. The strip of metal in front which is so displaced by the metal in the rear moves upwards and a little forwards before it is finally pressed down. This movement or change of the surface is very marked if the roller is heavy and the metal coat very plastic and thick. The new metal then swells up to a height so as to make it impossible for the roller to move forward. In the process of consolidation, the upper horizontal surface of the metal coat does not drop down, but turns into a wavy surface with a well-defined depth. As the process of consolidation advances, the depth of the corrugation gets less and less, and probably the pitch of the waves slightly increases, till in the end neither is visible to the naked eye. But all the same they are there in a lesser degree. If, however, the metal coat is trampled instead of by a roller the consolidation takes place by the metal moving down directly. If this is accepted, it follows that the depth of the waves will be negligible if (1) the roller used for interlocking the metal or the initial dry rolling should be a light one (2) the adherence between the new metal and the undercoat is effective, and (3) the new finished surface is not thrown open for traffic when it is green.

Mr. Syed Arifuddin (Hyderabad-Deccan) : There are two views with regard to the causes producing corrugation on roads. These are already mentioned in the paper. To know whether insufficient consolidation is responsible for corrugation or not, Mr. K. G. Mitchell, C.I.E., Consulting Engineer to the Government of India (Roads) had asked me about six months ago to conduct certain experiments. These have been carried out.

The first experiment was to pick up the old metal surface, add 3 inches metal coat and consolidate it with 12-ton roller in the usual manner.

In the second experiment, after picking up old surface and spreading the new 3 inches metal it was hand packed carefully and consolidated in the usual manner by 12-ton steam road roller.

In the third experiment after picking up old surface half the quantity required for 3 inches coat was first spread, then a layer of about $\frac{3}{4}$ inch moorum was spread over it; the remaining half quantity of metal was then spread over the moorum layer and consolidated with the 12-ton roller in the usual manner.

4th, 5th and 6th experiments were exactly the same as 1st, 2nd and 3rd respectively, except that the consolidation was done by hand ramming rammers weighing about 12 pounds.

It is nearly 5 months since the work was completed but no corrugation has developed up till now in any of the sections. The surface consolidated with hand rammers is not so even as that consolidated with steam road

roller. These experiments go a long way to prove that insufficient consolidation is not responsible for the corrugation. From what I have observed I find that few of the metalled roads but many of the moorum roads have developed corrugations. I am more inclined to believe in the theory that automobile traffic is chiefly responsible for this when a large number of automobiles passing over the road have more or less the same wheelbase. It will, therefore, be advisable to take a census of vehicles on those roads which show such corrugations to test this theory.

Mr. Dildar Hussain (Hyderabad-Deccan) : Members of the Indian Roads Congress have no doubt read a very interesting article written by Mr. E. P. Little, I.S.E., Executive Engineer, Nira Right Bank Canals Division, Poona, which appeared in the magazine " Indian Roads for April, 1936." The writer has made some very useful observations on the subject of road corrugations.

As Mr. Truscott has observed in his paper, it must be admitted that water-bound metalled roads with or without surface treatment are going to play an important part in our system of communications for many years to come, and therefore the question of corrugations brought about by the fast traffic has to be tackled by the road engineer.

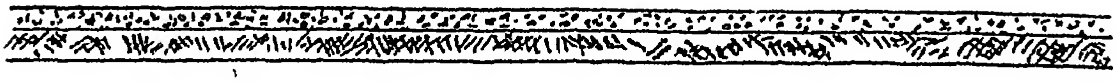
Now, as is well known, there are two types of corrugations—primary and secondary. The primary or the inherent one is obviously to be attributed to defective consolidation. If the surface is not picked properly so as to expose the sub-grade, the action that takes place is that during consolidation the front wheel of the roller pushes the metal forward, giving rise to the shape of a mound until the friction between the metal and the sub surface becomes so great as to stop the forward movement of the metal. The roller wheel mounts over this peak and passes forward, the descending motion causes a depression, while the rear wheel in passing over this peak and by its reaction helps in pushing this raised metal ridge behind. The ridge is thus formed due to a dual action. The ridges are no doubt small, but the result is that we get the road with an uneven surface.

The secondary corrugations may be ascribed mainly to the existence of excessive blindage on the road surface, and are the result of the spin of the wheel of the car and the action of the air spiral formed by the peculiar shape of the body of the car. Mr. Truscott has not mentioned anything in his paper as to what kind of roads are those on which he has made his observations. The corrugations noticed by him have been given to inidicate what is likely to happen to metalled roads in course of time. It is therefore probable that the roads he has referred to are not of metal.

The author observes that corrugation may be due to the friction of the wheels of fast moving motors slightly moving the whole metalling from its foundations or by the hammer action of the wheels crushing the under surface and destroying its bond with the soling or foundations and so allowing the metal to be rucked up like a carpet. If this were to be the case, we have to take it for granted that the road has reached such a stage of disintegration and that its breaking up is only a question of time. For, once the bond of the metal is shaken the metal crust by itself cannot long withstand the impact of the traffic. Metal will be loosened and the formation of potholes will begin. Mr. Truscott has thrown no light on the actual state of the road surface he has referred to.

Let us consider the surface of a mettalled road which has just been blinded, and on which no car has passed.

The surface will be like this :—



Now when a car passes over this surface, the same action takes place, viz., the formation of a peak at one place and a relative despression on the other. This despression is obviously superficial, although after the formation of corrugations it would appear as if the metal surface itself had undergone subsidence in one place and had risen in another. The shape taken by the blindage is somewhat as this:—

The vacuum formed under the pneumatic tyre at the point of contact, and the inrush of air at the sides, apparently causes the wearing of blindage which gives the appearance of corrugations as shown below :—

These peaks which have the section of a triangle are constantly under compression by the front wheel of the passing vehicle and the reaction of the rear wheel. This double compression leads to hardening of the blindage at these peaks The staff in charge of the road, noticing the corrugations add a further coat of blindage, but as there is no adhesion between the existing surface and the new blindage, the blindage is again pushed up, rolled and pounded, the ridges remaining where they were. The only effect is that for the time being the depression which had been subject to impact action gets a little respite.

The pitch of the corrugations as given by Mr. Truscott varies from 24 to 42 inches, while the depth varies from $\frac{3}{4}$ to $3\frac{1}{4}$ inches, *vide* Figure 2. In the case of the other road, the pitch varies from 24 to 39 inches and the depth from 1 to $1\frac{1}{2}$ inches, *vide* Figure 3.

I will give you a few results of my observations on a corrugated road surface :—

Case I.

Pitch of corrugations. Feet.	Inches	Depth of trough. Inch.	Thickness of blindage on the peak. Inch.	Depth of trough after removing the blindage peak Inch.
1	10	0·50	0·50	0·20
1	10	0·60	0·35	0 20
1	10	0·75	0 30	0·20
1	9	0·75	0·30	0 30
1	9	0·75	0 55	0·25

CASE II.
(on the same road)

Pitch of Corrugations Feet.	Inches.	Depth of trough Feet.	Inches.	Thickness of blindage on the Peak.	Depth of trough after removing the blindage Peak
2	4	0	90	Very little blindage.	
2	4	1	10		
2	6	1	00		

Road surface about to break up.

CASE III.

(on the same road on a culvert)

Feet.	Inches.		Inches.
2	10	Troughs	--
2	1	just	0·60
2	3	forming	0·75

With regard to the pitch of the corrugations, there appears to be a close relation between the kind of traffic and the pitch of the corrugations. In the case of a road subject to the traffic of heavy lorries, the pitch is likely to be more, say 24 to 30 inches.

If X = speed of vehicle in miles per hour

P = pitch of the corrugation in inches

$$\text{Speed} = \frac{X \text{ by } 5{,}280}{60 \text{ by } 60} = \frac{22\,X \text{ by } 12}{15} \text{ inches per second.}$$

Therefore time required to traverse a distance of P inches

$$T = \frac{P \text{ by } 15}{22X \text{ by } 12}$$

If X = 30 miles per hour

$$T = \frac{P \text{ by } 15}{22 \text{ by } 30 \text{ by } 12} = \frac{P}{22 \text{ by } 24}$$

Now if P = 22 inches, as in case 1

This gives $T = \frac{1}{24}$ second which corresponds probably more or less to the firing intervel of the engine at this speed when the torque is being transmitted to the back wheels. The same action is noticeable when steam enters the cylinder of the engine of the road roller and a correspon-ding pressure is developed on the back wheels giving them a tendency to spin.

If R = No. of revolutions per minute

F = No. of firings ,, $= \frac{R}{2}$

Therefore number of firings per second $= \frac{R}{2} \text{ by } \frac{1}{60}$

Or each firing interval $= \frac{120}{R}$

Therefore, if number of revolutions = 3,000

Firing interval $= \frac{120}{3{,}000} = \frac{1}{25}$ inch.

If the No. of revolutions is 2,000

the firing interval be $\frac{120}{2{,}000} = \frac{1}{17}$ second.

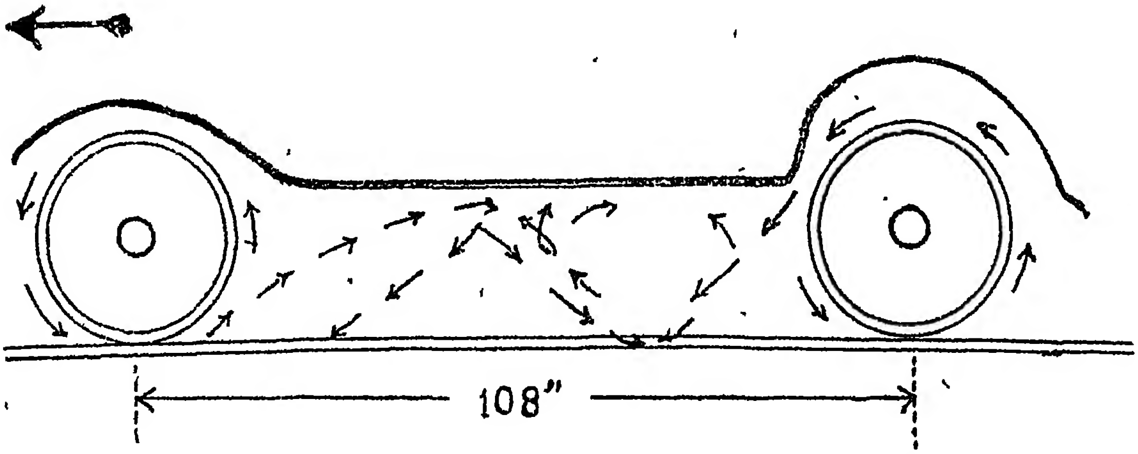
in which case the pitch is given by $\frac{1}{17} = \frac{P}{22 \text{ by } 24}$

or P = 30 inches.

This means that with high speed traffic, the pitch of the corru-gations will be small and for medium speed traffic, it will be more.

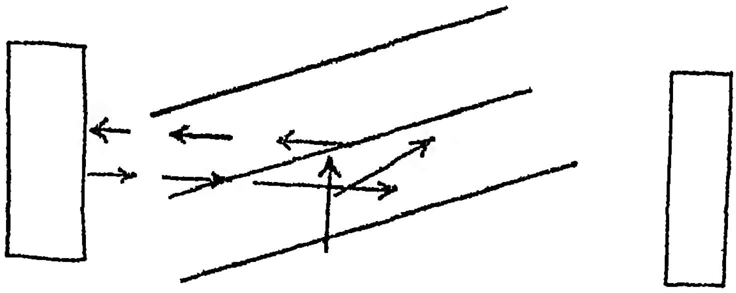
In the case No. II, which I have given, the pitch is 28 inches, but here there is no blindage and the troughs have formed into pot-holes and the road surface seems to be ready to break up. This appears

to be a case where the secondary corrugations have turned into primary corrugations and the subgrade has been shaken.



With regard to the formation of troughs the action of air which is set in motion by the movement of the car seems to be greatly responsible, the spiral motion causing the troughs, the axis of the spiral being at right angles to the axis of the road.

In case No. III which I have referred to, it was noticed that the corrugations were not at right angles but inclined at about 40 degrees to the axis of the road. The existence of the parapets of a culvert seems to account for this. The corrugations were somewhat as follows :—



It would therefore be interesting if a formula could be mathematically determined with the help of laboratory tests showing the relation between the speed of the traffic, the curvature of the air current and the trough.

The conclusion that follows is that corrugations are inevitable on a water bound macadam road under the existing conditions of traffic. They can however be minimised by a sparing use of blindage and also the kind of blindage. Moorum seems to be a great offender in this respect. It may perhaps be possible to invent some machine which may periodically clean the ridges and give a clean slate for blindage operations from time to time. There is a practice with some engineers to water the metalled surface before applying blindage. The belief with these people seems to be that a wet surface provides a good grip for the blindage and prevents its blowing away. It may be so, but the moist plane is bound to aggravate the formation of corrugations.

Rai. Sahib Fateh Chand (United Provinces) : I shall say only two things based on my experience. I have got two roads, one near my headquarters and the other farther away ; on one of the roads there is bullock-cart traffic and there is little corrugation. After sometime there

was heavy motor traffic on this road, and as soon as motor vehicles were put on the road there was corrugation. Subsequently the motor vehicles were removed and the corrugation was reduced.

In the case of the road near the headquarters, there were no irregularities in the surface of the road and it was noticed that there were fewer corrugations on this road. On the road away from the headquarters which had surface irregularities there were many corrugations. The initial irregularities in the surface are apparently responsible for the corrugations which develop.

To safeguard against the vibration caused by the speed on the surface of roads, perhaps one remedy is to provide cement concrete.

Mr. W. L. Murrell (Chairman): There is, unfortunately no time left for the further discussion of this very interesting subject.

There are several members who have something to contribute, and it is important that we should have their views. Would they please send these in, as soon as possible, to the Secretary in order that they may be published with the Proceedings of this Congress.

I understand Mr. Duraiswami Ayyangar will reply to the discussions on the paper.

Mr. S. G. Stubbs (President): The reply also may be written and forwarded to the Secretary.

This suggestion was agreed to.

Mr. W. L. Murrell (Chairman): I thank all the members who have spoken on this interesting paper so profitably and also those who are going to submit their views by post for insertion in the Proceedings under correspondance.

Mr. S. G. Stubbs (President): I propose a vote of thanks to Mr. Murrell who has occupied the chair during the discussion on this paper (*acclamation*).

CORRESPONDENCE.

I.—Comments made by Mr. C. L. Katarmal, State Engineer, Orchha State by post on Paper No. G.

Mr. Truscott deserves congratulations for bringing before this great body of road engineers a very important problem for discussion and opinion. I give below my experience in this concern :—

I am, at the moment, about to finish the remetalling of a fairly long bit of an old metalled road and I too had to face troubles due to the corrugation formed on the road surface at many a place during the progress of the work. In this case corrugations were seen one or two days after the consolidation when the surface was a bit dry. At first as usual I used a 15-ton steam road-roller for all operations of dry and wet rolling and this resulted in corrugations to a great extent. But to overcome this I used only the heavy roller for dry rolling and also after sprinkling sufficient water on the ballast, and then a 6-ton roller for the actual wet and final rolling. Corrugations then decreased to a great extent although they did not disappear totally and very slight vibrations are still felt while driving in a car. Some corrugations were formed by the jerks of the heavy road roller as it rolled during wet rolling and some were formed when light roller was used for dry rolling. At places they were formed where the foundation was of black cotton soil and the formation had no soling. Such portions were opened and redone with 9-inch thick stone soling in formations and 6-inch stone ballast for surfaces and reconsolidated

by the above process. The use of the light roller after the heavy one in this manner has added practically nothing to the cost of consolidation which has been, including all expenses of two rollers, about Rs. 1-6 per 100 cubic feet.

The road I have dealt with is about 40 years old and nothing beyond patch repairs was ever done to it. This is the first time that it is being remetalled with a 4-inch thick coat.

II.—Comments made by Mr. G. W. D. Breadon, District Engineer, Gurdaspur, by post on Paper No. G.

From observations I have made I have reached the conclusion that corrugation derives its origin at the time of rolling during consolidation. If watched closely it will be seen that the metal is subjected to both a downward compressive force and a forward raising thrust, the shearing action seldom carrying the metal forward for more than 24 inches to 30 inches according to the weight of the steam road-roller, after which the roller rides over the ridge and flattens it out a little. A 10-ton roller makes shorter waves than an 8-ton roller. Wave lengths also depend upon the thickness of metal spread on the road surface. The difference between the rise and the trough is not always perceptible to the naked eye, but the wave-like surface is there and since the positions of the rollers cannot be altered when reversing they will, on the return trip, perform the same processes in the opposite direction thus extending the waves and ultimately carrying them right across the road.

In my opinion this undulation exists on all metalled roads and as such the metal is not of uniform thickness, there is slightly more in the rises and slightly less in the troughs, which results in the formation of hollows and pot holes. No metalling is absolutely compact and homogeneous in texture and since the layer is wave-like it stands to reason that fast-moving traffic must deal a constant series of heavy blows on the troughs under which the waves must develop into corrugations distinctly perceptible.

I am of opinion that mere scarification of the surface, according to Public Works Department specifications, before the spreading of metal, is of little value; a scarifier drawn by a roller or tractor is still worse. What would, I think, counteract corrugation is herring-bone digging, the grooves to be not less than four inches deep and about three feet apart and filled with premix or concrete.

III.—Comments made by Mr. K. Tirrumalaiswami, District Board Engineer, Saidapet, by post on Paper No. G.

Corrugation is found only in certain portions and often times in well drained and good sub-grades. Traffic remains the same and spreading and consolidation exactly similar to those at other places, but nevertheless, corrugation appears in certain places only. In some cases, corrugation has appeared months after the consolidation was effected. It is generally found more on roads having heavy lorry or other motor traffic than on those having heavy cart traffic.

Most probably the corrugations are due to the kickback action referred to by the Chairman. This action will always be present and the construction of the road should be such that this action will not loosen the metal crust and drive the loosened portions backward and forward. A good adhesive binder will, to a large extent, provide such a surface. Painting alone cannot do this, as then the movement is driven a little lower. The best way seems to be to provide a good adhesive binder which will get round every piece of stone in the surface.

A heavy roller taken over a medium quality metal crushes the top layer, which for the time being gives a smooth surface, but under the suction of tyres, the movement above referred to becomes possible. It seems desirable to use a roller suited to the quality of metal.

IV.—Comments made by Mr. H. B. Parikh, Special Road Engineer in Sind, by post on Paper No. G.

Several members have already dealt with many of the points I wished to mention in connection with the formation of corrugations on road surfaces. It is clear from the discussion that roughness of the road surface combined with the pulsating pressure caused by fast moving vehicles is the main cause of their formation as stated by Mr. Daftary. I have observed that the roads recently improved in Ahmedabad are mostly free from corrugations. This is due to good foundation below the newly laid road surface, and great care taken in consolidating the surface by a roller. My friend Mr. C. C. Dangoria, Divisional Engineer, City Improvement Board Works (Hyderabad-Deccan) gave me as his experience that if traffic was allowed on a road immediately after consolidation, corrugations form within four days. The foundation and the road surface has no time to dry up in such a case and the cause of corrugations is obvious. Similarly I noticed on the road surface laid on a tank bund between Hyderabad and Secunderabad that it was uneven while similar surface on the approaches on both sides was quite satisfactory. This is a case of unstable foundations, as a tank bund is in its very nature liable to uneven settlement especially when the soil is loose, and it gives a clue as to how roughness of road surfaces over unstable foundations generally starts.

I have also noticed that when moorum is laid on a road in heaps and not evenly spread. corrugations on the surface are very quickly formed by fast moving traffic causing pulsating pressure. In one case I noticed that road coolies were removing rut marks by pulling tree branches across the road, and the small unevenness caused in blindage thereby was enough to start corrugations. The remedy in such cases is to sweep the road evenly as is being done in the Poona District as stated by Mr. Daftary.

All these cases go to show that if corrugations are to be avoided, the road surface should be maintained as smooth as possible and carelessness in rolling and unstable foundations should be avoided as far as practicable.

V.—Comments made by Mr. T. W. Stanier, of Messrs. Aveling-Barford Limited, by post on Paper No. G.

It is satisfactory to find that the consensus of opinion at this Congress is that road rollers are seldom the cause of corrugations in road surfaces. There appears to be general agreement that they are due to the action of certain types of traffic on the road and that they will occur, however smooth the surface of the road may be initially.

Nevertheless, the problem is one to which manufacturers of road rollers have devoted considerable attention, and as long ago as 1908, Messrs. Aveling-Barford supplied a number of 3-axle rollers which were designed to meet the objection sometimes raised that rollers tend to push the road metal in front of them, eventually forming a mound over which the wheels ride. The theory of the 3-axle roller was that when this occurred and the front roller had passed the high spot, the middle roll on which almost the whole weight of the roller would then be concentrated, would flatten out the high place when it reached it, thus leaving a perfectly level surface.

Unfortunately, such rollers, although there have been attempts from time to time to revive the design, have never been successful, since, apart from the extra complications involved, difficulty in steering and much higher first cost, the theory itself is unsound. Even though the 3-axle roller may leave a perfectly level surface, the material in the original high spot has obviously been consolidated by a much higher pressure than the rest of the road surface, with the result that under further consolidation by traffic, it again becomes a high spot. On the other hand, it sometimes happens that the pressure exerted by the centre roll is too high for the particular road metal with the result that the latter is crushed rather than consolidated, and subsequently disintegrates under traffic

Experience shows that the remedy is much simpler and lies in avoiding any tendency to the formation of such high spots, rather than in flattening them out once they have been formed. A little consideration will show that the larger the diameter of the roll the less will be the tendency for it to push the metal in front of it rather than to press it downwards. In other words, the larger the rolls the better, and obviously the greater the depth of consolidation the larger must be the diameter of roll.

Even in bituminous surfacing, however, with relatively thin layers of material, large rolls are essential, since the bituminous material is generally more plastic than ordinary road metal and has consequently a greater tendency to move laterally during rolling.

It is this necessity for large diameter rolls which makes the tandem roller unsuitable, for in most tandem designs, the frame and machinery are carried over the rolls with the result that the latter are inevitably smaller in diameter than the rolls of the conventional 3-wheel type.

Another disadvantage of the tandem type roller to which I should like to draw the attention of road engineers, is its relatively low pressure per lineal inch of roll, since the weight of the roller is distributed over two rolls, both of which extend the full width of the machine. In a 3-wheel roller on the other hand, about two-thirds of the gross weight is carried by the rear axle, and distributed over the two relatively narrow rear wheels, with the result that the pressure is very much higher than in a tandem of similar gross weight. In actual practice the pressure of a normal 5-ton 3-wheel roller is about the same as that exerted by an 8-ton tandem. I suggest that the use of the tandem roller, which was at one time very popular, may sometimes be responsible for corrugations being formed, owing to the light pressure such a roller exerts.

At one time it was suspected that the single cylinder horizontal slow-speed diesel roller was more likely to start corrugation, than the multi-cylinder high speed vertical type, but it is now generally agreed that with improved balancing and smoother torque, this fear is not borne out in practice, and owing to its simplicity, slower working speed, smaller number of working parts and greater reliability, the single cylinder engine is much more suitable for road roller duty. This is particularly the case in India where maintenance methods are often crude, and where the greater familiarity of mechanics with the slow speed engine is a big factor in obtaining satisfactory results.

I should like to make it clear that I have no bias in urging the claims of the single cylinder type of roller as compared with the tandem or multi-cylinder machine. Of all the three types of rollers manufactured, experience shows that the single-cylinder three-wheel roller gives the best results.

In conclusion, I should like to refer to two devices that are almost standard fittings elsewhere, though seldom used in India, which, I believe,

might frequently be used to mitigate or eradicate corrugations, i.e., sprayers and scarifiers. Practically every roller one sees in India is surrounded by a bevy of women holding wet sacks against the wheels or throwing water on them from *chatties.* I have heard it suggested that this often results in the water reaching the road in irregular splashes, thus forming soft patches. The use of a sprayer on the other hand, consisting simply of a water tank on the roller, and sprinkler pipes fed by gravity over each roll, results in absolutely even watering.

Nothing need be said about scarifiers, as their advantages for ripping up a badly corrugated road are self-evident. One is usually told in India that coolie labour is cheaper, but I am convinced that in many districts the use of a scarifying attachment would result in reduced costs, as well as in more satisfactory work.

VI.—Comments made by Mr. E. A. Nadir Shah, Bombay Municipality, by post on Paper No. G.

The author only deals with corrugations in waterbound-roads. The corrugations illustrated in figures 2 and 3 are due to the road crust being not thick enough to distribute the load on a bigger area. The fact that the surface which was good enough for light traffic now corrugates on account of heavy traffic shows that sub-grade is not strong enough to resist the pressure produced on a unit surface and therefore yields. Mr. Radice, while commenting on the papers, has given a very good example of Corrugations in Rail Roads which shows that surface is not to be blamed for corrugation. As a remedy I would suggest to scrape up the corrugated surface to the depth of corrugations and re-roll the same material with a heavier roller. On this new surface thus formed, spread another 4 inches of gravel and roll with a heavy roller. The process to be repeated if necessary.

During discussion of the paper various causes of corrugations were given by different speakers but most of the causes given are beyond our control, such as load, speed, impact, etc., etc., so the question again boils down the design of roads against corrugations.

VII.—Reply by Mr. M. S. Durraiswami Ayyangar, on behalf of Mr. G. B. E. Truscott, (Author) to the Comments made on Paper No. G.

It is indeed gratifying to see that this paper on "Corrugations on Road Surfaces" by Mr. Truscott has, as anticipated by the author, provoked such a long and extended discussion among members of Road Congress that the discussion had to be left unfinished in the session for want of time. As desired by the author, I take this opportunity of replying to the discussions by this short written note.

With the advent of fast-moving vehicles, the road engineer is everywhere faced with the additional problem of road corrugations and this is evidenced by the keen interest taken by so many members coming forward to enter into the discussions.

Speaking for myself, the first occasion when I noticed corrugations on a road surface was about fifteen years ago when as a casual visitor to the State of Pudukottah, in Madras Presidency, I saw the motor road between Trichinopoly town and Pudukottah—a distance of 33 miles with heavy corrugations on its surface. There were at that time two tracks on that road running side by side, one for ordinary bullock-cart traffic and the other reserved for motor traffic. The corrugations were seen only on the motor portion of the road and none on the cart track.

Since then, I had to tackle this problem personally only during the last two or three years in some of the Travancore roads in my charge.

Various theories have been advanced by the several members during the discussion and the most plausible is that corrugations are the result of the creeping of the under surface due to the pressure transmitted to it through the top layer which gets separated from the bottom owing to the tractive resistance of vehicles with heavy speeds. I may, however, point out the following facts regarding the appearance of corrugations to which I believe most members will agree.

1. They appear on all classes of roads to a greater or lesser degree. One member said that they are present even in concrete roads. This seems to suggest that the hardness of surface material has very little relation to the formation of corrugations.

2. When they do occur, they do so at fairly regular intervals.

3. In the same road and under exactly similar conditions, they are found to be less prominent at curves than in straight reaches, thus suggesting that the speed of vehicles is a great factor in determining the degree and frequency of corrugations.

4. They are more prominent in portions of road which run in embankments than in sections which are in cutting. This appears to suggest that the bottoming or soling of the roads is an important factor in the formation of corrugations.

Mr. Katarmal (Orchha State) has stated that corrugations were due to the use of a heavy roller for remetalling work where the soil was black cotton, and where the road had no proper soling. Mr. Breadon and some others derive the origin of corrugation right to the time of rolling during consolidation. Many other members also attach importance to the degree of consolidation and the weight of the roller as contributing causes of corrugations. It appears no doubt true, that sound consolidation delays the formation of corrugations, but I do not personally think that poor consolidation is responsible for its formation as suggested by Mr. Dildar Hussain and some others. The use of light rollers at the time of rolling especially when the sub-soil is weak lessens the tendency to corrugate. As pointed out by the Chairman, we cannot totally eliminate corrugation. Our efforts are primarily directed towards finding ways and means to minimize it. Mr. Guha has suggested tarring or bitumen treatment as a remedy to resist the formation of corrugation. Mr. Fitzherbert of Bombay considers that moorum-blinding is less susceptible to corrugations than sand-blinding. It appears, however, that all corrugations due, if at all, to poor consolidation or use of poor blinding material, should also be capable of rectification by reconsolidation repeated with a light roller using more blinding material after profuse watering of the surface. But the real trouble appears in places where the soling is defective, when no amount of surface remedies seem really, sufficient.

Proper drainage of the underground soil and the formation of a sufficiently thick layer of bottoming material to withstand the impact brought to bear on the road surface appear to be only sure remedies to minimise these corrugations.

One other point in the paper which does not seem to have evoked much of criticism is the use of girder section in roads as a means of lessening the corrugation. In most country roads it is the centre portion which takes most of the volume of the traffic and very often, we have two wheel tracks each about 2 feet wide spaced about 4 feet 6 inches to

5 feet centres. If the material in these wheel tracks be made thicker than in the rest of the road, they are found more capable of resisting the formation of corrugations. Recently some experiments have also been made in Travancore by using 4½ inches thick broken metal for the wheel tracks only in a gravelled road which was hitherto subject to heavy corrugation and these promise to be successful.

I wish to reply to Mr. Dildar Hussain (Hyderabad) that both the roads selected by the author are gravelled roads only with no special bottoming.

I agree with Mr. Tirumalaiswami in his conclusion that a good adhesive binder and the use of a roller suitable for the quality of metal will minimize corrugations to an appreciable extent.

It is true that the coming on of heavy traffic on a recently reconsolidated road before the foundations had had time to dry up, results in the formation of corrugations and it is therefore necessary that unstable foundations should be avoided and road surface maintained carefully till then.

With regard to Mr. Stanier's observations I would say that the rollers in use in Travancore are mostly of 3-wheel type and these have been giving satisfactory results in rolling and we have had no difficulty with regard to uniformity of watering or in scarifying.

VIII.—Addendum by Mr. G. B. E. Truscott (Author) to the replies given on his behalf by Mr. M. S. Durraiswamy to the comments made by members on Paper No. G.

It is gratifying to me that my paper provoked such an extended discussion. No final solution seems to have been arrived at and I am not sure that I have one to offer, but during my recent visit to England I particularly observed the roads there and could not see any signs of corrugations although those roads were subjected to much heavier, faster and intensive traffic than roads in India. English roads, I believe, are generally constructed of heavy soling with thick metalling and nowadays practically all are at least surface treated.

In India soling is not usual and the metalling is usually thin and so it may be possible that the metalling is not thick enough to transmit the loads it has to bear and so the joints between the metalling and sub-grade become separated and with the wheels of fast-moving vehicles tending to ruck up the metalling in the same way that a carpet is rucked up on a smooth floor, corrugations are started.

So the prevention of this would, therefore, appear to indicate that wherever possible soling should be used with an adequate thickness of metal, properly laid and consolidated, and if this is not possible on account of cost, girder sections should be used which would carry the bulk of the traffic, and also by their greater depth prevent the thinner sections from moving.

APPENDIX I.

Tours and other functions held during the Fourth Session of the Indian Roads Congress, Hyderabad (Deccan), January 1938.

Saturday, January 1, 1938.

The delegates assembled at Hostel A at the Osmania University Buildings, Hyderabad (Deccan), at 8-30 a.m., and proceeded from there in buses to inspect the roads leading to and certain other engineering works near the Sewage Disposal Works and Farm at Amberpet. They returned to their respective lodgings at 12-30 p.m. for the lunch.

In the afternoon the delegates re-assembled at 3 p.m at the Hostel. From there they were taken in buses for a visit to Improvement Works in Hyderabad City, poor houses, etc In the evening at 5 p.m. the Honourable Raja Rajwant Sham Raj Bahadur, Member-in-Charge, H. E. H. The Nizam's Public Works Department, was " At-Home " to the delegates. The delegates left the residence of the Honourable Member at 6 p.m.

An account of the BANQUET which was held on the same night will be found in Appendix II.

Sunday, January 2, 1938.

On the 2nd January, 1938, the delegates assembled again at 8-30 a.m. at the Hostel whence they proceeded in buses to inspect the roads specified below :—

1. LINGAMPALLI GARDEN & MUSHIRABAD CEMENT CONCRETE ROAD.

Length ...	2,640 feet
Width ..	40 feet
Thickness—Top course ...	8 inches
Bottom course...	6 inches, 3 inches, 6 inches.

Size of material :—

Coarse aggregate of granite—

$2\frac{1}{2}$ inches to 2 inches	75 per cent.
$1\frac{1}{2}$ inches to 1 inch	25 per cent.

Fine aggregate of clean river sand 1/8 inch and less.

Proportions—Top course $1 : 1\frac{1}{2} : 3\frac{1}{2}$

Bottom course $1 : 3 : 5$

This was constructed in 1935 and has been laid over the old moorum surface. Heavy bus and cart traffic between Hyderabad and Secunderabad and the Industrial area ply over this.

The cost per square yard was Rs. 1.

2. MUZAMJAHI ROAD & MUSHIRABAD CEMENT CONCRETE ROAD.

(a) Length ..	1,710 feet
Width ...	20 feet
Thickness—Top course ..	8 inches
Bottom course..	6 inches-3 inches-6 inches.

Size of material (same as for 1).

Proportion—Top course $1 : 2 : 4$

Bottom course $1 : 3 : 5$

This was constructed in 1930 and was laid over the old moorum surface. Heavy bus and cart traffic between Hyderabad and Secunderabad and the Industrial area ply over this.

The cost per square yard was Rs. 4-12 due to the higher price of cement.

(b) Experimental Bits—

	Bit 1.	Bit 2.	Bit 3.
Length ...	60 feet	60 feet	60 feet
Width ...	38 feet	19 feet	19 feet
Thickness ...	3 inches	6 inches	6 inches

Size of material (same as above).

	C S A	C L S A	L S A
Proportion—	1 : 2 : 4	1 : 1 : 5 : 8	1 : $2\frac{1}{2}$: 5

Bit 1. This was laid in 1935 on the old water-bound spramax treated surface after removing top 3-inch surface. Cost per square yard was Rs. 2-6.

Bit 2. This was laid in 1937 after removing 6 inches of the old water-bound spramax treated surface. The top surface was painted with tar.
Cost per square yard including tar painting was Rs. 3-12

Bit. 3. This was also laid in 1937 after removing 6 inches of the old water-bound spramax treated surface. The top surface was painted with tar.

Cost of square yard including tar painting was Rs. 2-10.
The traffic on the above three bits is moderate and mixed.
Asphalt Shellcrete Road.

3 inches Shellcrete work with Shellmac and Spramax, 1 mile long and 24 feet wide.

$1\frac{1}{2}$ inches to 1 inch metal and fine sand passing through 1/8 inch sieve was mixed in proportion of 5 : 3 : 3 pounds of Maxphalt was added to one cubic foot of metal and 8 pounds of Shellmac to 1 cubic foot of sand and mixed. The mixture was rolled when still hot with a ten-ton roller. This was constructed in 1934-35.

3. Putli Bowdi Cement Concrete Road.

(a) Putli Bowdi to Afzulganj Mosque.

Length ... 3,500 feet.
Width ... 20 feet central belt of cement concrete.
20 feet side berms of lime concrete.

Thickness—	Central belt.	Side berms.
	Top course 3 inches	6-inches lime-
	Bottom course	Cement Concrete
	6 inches-3 inches-6 inches.	

Size of material (same as above).

Proportion	Central belt.	Side berms.
Top course	1 : 2 : $3\frac{1}{2}$	1 : 1 : 5 : 8
Bottom course	1 : 3 : 5	

This was laid in 1929 over the old moorum road surface. Heavy bus traffic passes over this. The cost per square yard of central belt was Rs. 4-12 and side berms Rs. 3-4-0.

(*b*) Putli Bowdi to Muzamjahi Market.

Length ... 2,288 feet
Width ... 20 feet central belt with side berms of moorum.
Thickness ... Top course 3 inches
Bottom course 6 inches-3 inches-6 inches.
Size of material (same as above).

Proportion—Top course $1 : 1\frac{3}{4} : 3\frac{1}{2}$
Bottom course $1 : 3 : 5$

This was laid in 1934 over the old moorum road surface. Mixed bus and cart traffic pass over this. The cost per square yard was Rs. 4 Putli Bowdi to Rangmahal Road.

(*c*) Penetration macadam and surface painting works.

3 inches penetration treatment with Socony asphalt on 6 inches water-bound macadam.

Length ... 800 feet
Width ... 40 feet

This was constructed in 1929. No maintenance has been done so far. Heavy goods traffic from the Railway Station passes over this. The surface bleeds much in summer, and needs fresh coat of coarse sand every year.

(*d*) A soling of 6 inches is provided. Over this 6 inches water-bound macadam is done and after the road was opened to traffic for three months it was surfaced with spramax in 1930. It was resurfaced with flux oil and shellmac in December 1937.

Traffic condition same as above.

4. Puttargutti Cement Concrete Road (Afzalgunj to Charminar).

Length ...3,945 feet.
Width ...20 feet central belt.
10 feet additional central belt on either side.
20 feet lean cement concrete side berms on either side.

Thickness—*Central belt.*		*Addl. Cen. Belt.*	
Top course	3 inches.	Top course	3 inches.
Bottom course	6 inches-3 inches-6 inches.	Bottom course	3 inches.

Side berms.

Top course ... 3 inches
Bottom course ... 3 inches

Size of material (same as before).

Proportion.	*Central belt.*	*Addl. Cenl. Belt.*
Top course	$1 : 2 : 3\frac{1}{2}$	$1 : 1\frac{3}{4} : 3\frac{1}{2}$
Bottom course	$1 : 2\frac{1}{2} : 4$	$1 : 2\frac{1}{2} : 5$

Side berms.

Top course ... $1 : 2\frac{1}{2} : 5$
Bottom course ... lime concrete.

The central 20 feet belt was constructed in 1929 and the additional 10 feet sides as well as the side berms were constructed in 1931. There is mixed heavy traffic over this.

The cost per square yard of the central belt is Rs. 4-12
and additional 10-feet belt Rs. 4-4
and side berms Rs. 3-4

Charminar, Puranapul, Afzalshahi Road.

5. Afzalgunj Mosque Tar and Asphalt Bus Roads.
Same as bits 2 and 3 under item (2) and 3(*d*).

6. Mukkaram Jahi Cement Concrete Road.

Length	...	3,000 feet
Width	...	20 feet
Thickness—Top course	...	3 inches
Bottom course	...	3 inches

Size of material (same as before).
Proportion—Top course $1 : 1\frac{3}{4} : 3\frac{1}{2}$
Bottom course $1 : 2\frac{1}{2} : 5$

This was constructed in 1935 and laid in the old tank bed over 6 inches of laminated stone soling. Very heavy goods traffic (lorries and carts) pass over this from and to Hyderabad (B. G.) Rly. station. The cost per square yard was Rs. 4.

Note.—Traffic census taken by the Department of Works, City Improvement Board, Hyderabad-Deccan, is given in Annexure A.

7. Punjagutta Experimental Bits of Cement Concrete Road.

(1) Length	...	330 feet and junction
Width	...	10 feet
Thickness—Top course	...	3 inches
Bottom course		3 inches

Size of material—Top course. (Same as before).
Bottom course Coarse aggregate of old metal from existing surface. Fine aggregate of clean river sand.
Proportion—Top course ... $1 : 2 : 4$
Bottom course ... $1 : 2\frac{1}{2} : 5$ (lime concrete)

The old water bound macadam surface is excavated and the metal therefrom used for the bottom course.

(2) Length	...	330 feet
Width	...	10 feet
Thickness	...	3 inches

Size of material (same as above).
Proportion—$1 : 2 : 4$

The old water-bound macadam surface was picked lightly to remove the top layer of metal and cleaned of all loose materials, brushed and washed.

(3) Length	...	330 feet
Width	...	10 feet
Thickness	...	5/8 inch

The water-bound metal surface was laid for the first time over the old moorum road about a year and a half ago and the surface was in good condition. The first coat of Shalimar Tar No. 1 was applied at the rate of 3 square yards to a gallon or about 44 pounds per 100 square feet and covered with granite chips (1/2 inch) and rolled with a 6-ton Tandem roller.

The second coat of Shalimar Tar No. 2. was applied after two months at the rate of 10 square yards to a gallon or about 13 pounds per 100 square feet. The first half length was covered with 1/8 inch granite chips and the

second half with river sand and rolled as before.

Work in progress—

(4) Length ... 330 feet
Width .. 10 feet
Thickness ... 5/8 inch

Over the existing water-bound metal surface two coats of surface painting with spramax (Burmah Shell) has been done. The first coat is at the rate of 3 square yards to a gallon or about 38 pounds per 100 square feet and covered with 1/2 inch granite chips and rolled.

The second coat is done at the rate of 5 square yards to a gallon or about 23 pounds per 100 square feet. Half the length is covered with 1/8 inch granite chips and the other half with sand and rolled.

Work in progress—

(5) Length ... 330 feet
Width ... 10 feet
Thickness ... $2\frac{1}{2}$ inches

The bottom layer 2 inches thick consists of premixed metal $1\frac{1}{2}$ inches gauge, 3 pounds of Shalimar Tar No. 2 per cubic foot of metal covered with a layer of premixed metal 1/2 inch gauge and Shalimar Tar No. 2 in the same proportion were simultaneously rolled with a 10-ton roller. The premixed materials were cured from 7 to 10 days. This is proposed to be covered with a wearing coat of premixed 1/4 inch granite chips.

The work is in progress—

(7) Length ... 330 feet
Width ... 10 feet
Thickness ... $2\frac{1}{2}$ inches

1 inch metal and 1/8 inch sand in the ratio of 5 : 3 by volume are mixed with asphalt (Mexphalt and Shellmac 2 : 1). Asphalt was added at the rate of $3\frac{1}{2}$ pounds to a cubic foot of metal and 9 pounds per cubic foot of sand laid hot and rolled immediately with a 10-ton roller.

(8) Proposed experimental bits.

(*a*) Length ... 330 feet
Width ... 10 feet
Thickness ... $2\frac{1}{2}$ inches

This is a premixed cement concrete macadam (1 : $2\frac{1}{2}$: 5) with a water ratio of 4·3 gallons per bag consolidated with a 6-ton roller.

(*b*) Length ... 500 feet
Width .... 15 feet
Thickness ... 6 inches
Size of metal ... $2\frac{1}{2}$ inches

(*c*) Length ... 500 feet
Width ... 15 feet
Thickness ... 6 inches
Size of metal ... $1\frac{1}{2}$ inches

(*d*) Length ... 500 feet
Width ... 15 feet
Thickness ... 6 inches
Size of metal ... $2\frac{1}{2}$ inches to 1/2 inch stepped by 1/2 inch and mixed in equal proportions.

(*e*) Length ... 500 feet
Width ... 15 feet
Thickness ... 6 inches
Size of metal ... 2 inches to 1/2 inch stepped down by 1/2 inch and mixed in equal proportions

(*f*) Length ... 500 feet
Width ... 15 feet
Thickness ... 6 inches
Size of metal .. $1\frac{1}{2}$ inches to 1 inch stepped down by 1/2 inch and mixed in equal proportions.

The mixing for (D), (E) and (F) bits is effected by stacking the metal in layers, the bottom layer being followed by the next smaller size. The metal was taken from such stacks by spades in small cuts allowing the metal from different layers to fall and get mixed. The baskets were then filled with forked shovel and the metal laid lightly on the formation to prevent segregation. These experiments are being carried out to determine their suitability or otherwise.

8. New experimental road under construction from Lakdi-ka-Pul to Masab Tank.

Length ... 8,580 feet
Width ... 20 feet
Thickness .. 4 inches-3 inches-4 inches
Proportion—1 : 2 : 4.

The cement concrete road is being laid on the old water bound macadam surface. It is found that due to the varying camber of the old road it is not possible to confine the section to 4 inches-3 inches-4 inches, but has to be increased in some places to 6 inches-3 inches-6 inches. At such places a leaner bottom course in proportion of 1 bag of cement to 4 of sand and 8 of old metal is provided.

At 12-55 p.m. the delegates returned to their lodgings *via* Hussainsagar bund south-end, Basheerbagh and Workshop road to University.

The delegates re-assembled at the University Hostel at 2 p.m. and proceeded in buses to inspect the following:—

1. Filter Beds at Asafnagar and the experimental Trackways en route.
2. The Dams at, and the roads leading to, Himayatsagar and Osmansagar.

Tea was served at Osmansagar Gardens at 5 p. m. The delegates returned to their lodgings at about 7 p.m.

Monday, January 3, 1938.

The delegates assembled at 7 a.m. at the University Hostel and proceeded in cars and buses towards Nizamsagar *via* Pacharam for the inspection of rural roads. Cement Concrete trackways, experimental waterbound roads for the investigation of "corrugation," and rural development road to Banswada village were also inspected. The Nizamsagar Dam and the Sugar Factory near Nizamabad were inspected en route.

Lunch was served at Nizamsagar Guest House and tea at Ali Sagar Lake. On the way back, dinner was served at the Town Hall, Nizamabad.

The details of roads inspected are given in Annexure B. A note on the rural development road to old Banswada village is contained in Annexure C and general information about the roads in Hyderabad will be found in Annexure D.

A route map is on page 26.

ANNEXURE A.

TRAFFIC CENSUS

Noted by the Department of Works City Improvement Board, Hyderabad (Deccan).

MUKKARAM JAHI ROAD, HYDERABAD.

Taken on 4-8-37 from 7 a.m. to 7 a.m. (24 Hours).

Width of the road.—40 feet Cement Concrete in the centre and 20 feet of berms (muram) on either side.

Type of Vehicle.	From Station to City. Incoming.		From City to Station. Outgoing.		Total.
	Day.	Night.	Day.	Night.	
SLOW MOVING.					
1 Bullock-carts loaded (Double)	138	30	368	79	615
2. „ „ empty „ ...	290	65	89	24	468
3. „ „ loaded (Single)...	126	3	163	8	300
4. „ „ empty „ ...	158	16	97	15	286
5. Hand-carts	20	1	38	2	61
FAST MOVING.					
6. Lorries railway	6	3	9	1	19
7. „ Private	23	...	20	2	45
8. Buses „	18	3	12	1	34
9. „ railway	3	5	5	2	15
10. Motor cars	453	113	425	125	1116
11. „ Cycles	33	10	35	7	85
12. Tongas	536	170	561	156	1423
13. Cycles	2257	630	2579	665	6131

TRAFFIC CENSUS.

Taken on SULTAN BAZAR ROAD from 7 a.m. to 7 a.m. (24 hours). Width of the road 20 feet.

	Type of Vehicle.	Weight of Vehicle in Tons.	In-coming.	Out-going.	Total.	Total in Tons.
	SLOW MOVING.					
1	Bullock-carts (loaded) Double	1½	69	63	132	198
2.	,, ,, (empty) ,,	½	40	39	79	39·5
3.	,, ,, (loaded) Single	1	40	63	103	103·0
4.	,, ,, (empty) ,,	¼	57	35	92	23
5.	Hand-carts ...	¾	35	46	81	60·75
	Total ...	...	...	...	...	424·25
	Equivalent number of loaded double bullock-carts=282					
	FAST MOVING.					
6.	3-ton lorries loaded ...	5	49	23	72	360
7.	,, ,, empty ...	2	...	...	..	...
8.	2 ,, ,, loaded ...	4	175	172	347	1388
9.	,, ,, empty ...	2	...	...	...	...
10.	Motor Cars	1	466	420	886	886
11.	Motor Cycles	1/8	43	36	69	9·87
12.	Tongas	⅓	641	566	1207	401·73
13.	Push Cycles	1/10	2837	2738	5575	557·5
	Total ...	...	...	...	...	4103·12

Equivalent number of 1-ton motor cars ... 1855

Equivalent number of 4-ton loaded buses ... 437

Total Traffic load 424·25 plus 4103·12=4527·37 tons.

Average load per foot width of the road. 226·368 tons.

UPPER TANK BUND ROAD.

Nature of Vehicle.	Nos.	Approximate Weight in tons.	Total Weight in tons.	Width of road.	Weight per yard width per day.
1. Motor Car ...	2501	1·5	3751	7 yds	535·6
2. „ Cycles ...	323	1/5	64·6	,,	9·14
3. Buses N. S. Rly.	308	4	122	,,	175·42
					720·16

On this road no heavy traffic like bullock-carts is allowed.

As the shelsheet is laid only in the centre and there are side strips of over 20 feet width, traffic like push cycles and tongas are confined to them and so their account is ommitted from above.

ANNEXURE C.

A brief note regarding the construction of rural development road to old Banswada Village.

General.—The village of Old Banswada is connected to the Nizamabad-Nizamsagar P.W.D. Road, in mile No. 30. The road is aligned on the ridge, as far as possible. The soil met with is *chowka* with black cotton soil up to the village as the road is surrounded on both sides by fields having wet cultivation of paddy and sugarcane. To protect the road from the wet cultivation, an average banking of 1½ feet is given for a length of 21 chains.

The length of the road is 40 chains. The width of the road is kept 18 feet inside to inside of side chains. The moorum width is 12 feet only. In the beginning, 6 inches moorum was provided and consolidated with bullock rollers. The cost of construction was Rs. 1,100, cost per mile being Rs. 1,452 only. This cost is slightly more than the average, owing to the height of banking required in this case.

Drains and Culverts.—The irrigation drains are provided with hume-pipes 12 inches diameter. One 18-inch hume-pipe culvert is provided near the village to drain off the water from the village.

Gradient.—From ch. 0 to ch. 5, a gradient 1 in 800 has been allowed, and then the level portion comes up to chainage 15. From chainage 15 to 20, a gradient of 1 in 150 is allowed.

The road was constructed in 1931. Maintenance of the road was again done in 1934 at a cost of Rs. 530. In 1937 maintenance was done at a cost of Rs. 683 and the cost of the 18 inches diameter. Hume pipe culvert was Rs. 134.

On account of the Rice Mill situated along this road, the traffic on the road is heavy. The carts from the adjoining villages also bring their produce of paddy to this Mill. Exact census of the carts has not been recorded but an average number of 100 loaded carts per day may be taken to use this road during the season. The surface has withstood this traffic satisfactorily.

SHORT SUMMARY.

1. Soil *Chowka* with black cotton soil.
2. Length - - 6 furlongs
3. Width - - 18 feet
4. Moorum width- 12 feet
5. Cost - - Rs. 1,100
6. Cost per mile - Rs. 1,452

1931

ANNEXURE D.

DISTRICT ROADS IN HYDERABAD STATE.

The total area of the Hyderabad State, 82,698 square miles may roughly be divided into two parts, the South Eastern and the North Western. The former is Granitic and the latter Trappean. The soil in the former is formed from disintegrated granites and gneisses and is gravelly. The soil in the latter is generally black cotton.

The total length of the State Roads, exclusive of Local Fund Roads, is over 5,000 miles. Of this not less than 3,000 miles consist of metal roads intended for fast and heavy traffic, while the rest of the roads are of moorum. The total length of roads works out to 1 mile for every 16 square miles of the country.

In the granitic areas roads are economically constructed with gravel surface, but if traffic is heavy a 6-inch layer of water-bound granite metal is laid on the existing gravel surface.

In the Trappean country it is difficult to construct roads on account of the black cotton soil, which becomes slushy very quickly during the rains and develops wide cracks extending to a depth of about 12 feet in other seasons. On a road embankment formed of this soil, gravel cannot be used for surfacing, for the above reasons. Besides, gravel is not easily available. Necessarily, therefore, roads in these parts need a metal surface laid over stone soling.

Thus it will be seen that, in this State, roads in open country can be classified as follows :—

1. Granitic Country :—
   (*a*) roads with gravel surface.
   (*b*) roads with metal surface.
2. Trappean Country :—
   Roads with metal surface laid over stone soling.

METHODS ADOPTED FOR CONSTRUCTION.

The roads are generally taken in embankments varying in height from 9 inches to 2 feet excepting at approaches to culverts or bridges. High banks being dangerous to cart traffic, upright stones are fixed at the edges of the road to prevent accidents. The stones are fixed 4 feet apart centre to centre, their height above the road surface being 3 feet. This precaution is taken wherever the height of the bank exceds 3 feet.

Due to the flat nature of the country it is not generally necessary to take the roads in cutting excepting when hilly tracts are to be negotiated. The ruling gradient in such cases being limited to 1 in 20.

The alignment of roads is taken straight as far as possible, but as every road has necessarily to touch the towns and villages enroute, a continuous straight line is not practicable. The road has therefore to change in direction from place to place. The change of direction involves the introduction of curves, the minimum radius being 500 feet. This is necessary in view of the motor traffic.

The work of constructing the road surface is carried out in the following manner :—

I. (*a*) Roads with gravel surface. When the formation is ready, a 6 inches coat of gravel is laid to the proper camber and consolidated by a 3-ton bullock roller !

(*b*) If the intensity of traffic is found to be heavy, a metal coat 6 inches thick is laid over the gravel surface with cross camber of 1 in 36. The metal is generally of $1\frac{1}{2}$ inches gauge. After the layer is spread the metal is consolidated.

II. In the Trappean area where the soil is of black cotton type the metal coat is laid on stone soling. The stone soling consists of well packed rubble stones varying in thickness from 6 inches to 9 inches laid on the sub-grade The soling is dry-rolled to form a hard bed for the metal coat.

CLASS OF ROADS.

According to their importance, roads are classified as under :—

1st Class.—Roads connecting large trade centres and commercial outlets.

2nd Class.—Roads connecting principal markets with main lines of a road or short Railway Feeder Roads or those connecting administration headquarters.

3rd Class.—Village roads with light traffic.

The Principal features of these are tabulated below :—

Class of roads.	Width of road in feet.	Width of wearing surface in feet.	Width of side berms in feet.	Width of road at culverts in feet.
1st Class ...	30	15	$7\frac{1}{2}$	21
2nd „ ..	24	12	6	18
3rd „ ..	21	9	6	15

For constructing new roads, the following widths of land are generally acquired :—

Class of Road.	Width in dry land.	Width in wet land.
1st Class	99	66
2nd „	66	44

COST OF ROADS.

The cost per mile inclusive of bridging streams below 15 square miles in drainage area generally works out as follows :—

Class of roads.	Gravel roads.	Granitic area.	Trappean area.
	Rs.	Rs.	Rs.
1st Class .. .	8,300	11,000	15,500
2nd „	6,800	10,000	13,200
3rd „	4,000	6,200	8,200

The life of roads with different surface coats varies with the intensity and kind of traffic and the nature of surface. From experience it has been found that the surface needs renewal after a period of about five years and even less if the traffic is heavy, depending upon other contributory factors.

The system of maintenance is therefore so arranged that the surface is renewed by rotation within a period of five years. The usual thickness of renewal coat for metalled surface varies from 3 to 4¼ inches while for gravel it is 3 inches to 4 inches.

Roads are maintained by means of patch repairs and through permanent gangs of coolies (workmen). A gang consisting of 7 to 9 coolies helped with a bullock-cart is entrusted to look after a stretch of 5 to 7 miles length of road according to its class as shown in the following table. The duties of a gang are (1) to keep the surface blinded with sand or moorum, (2) to do patch work in the broken portions, (3) to keep the berms in a tidy condition.

The following table gives the strength of gangs on each class of road :—

Class of roads.	Coolies.	No. of Coolies.		No. of miles to be looked after per gang.
		Metalled road.	Gravel road.	
I	Head Cooly ...	1	1	
	Men Coolies ...	3	4	
	Women " ...	3	4	
	Cart ...	1 cart for 6 months	1 cart for 9 months	5
II	Head Cooly ...	1	1	
	Men Coolies ...	2	3	
	Women " ...	2	3	
	Cart ...	1 cart for 6 months	1 cart for 9 months	5
III	Same as for 2nd class ...			7

Cost of maintenance per mile per annum is given below.

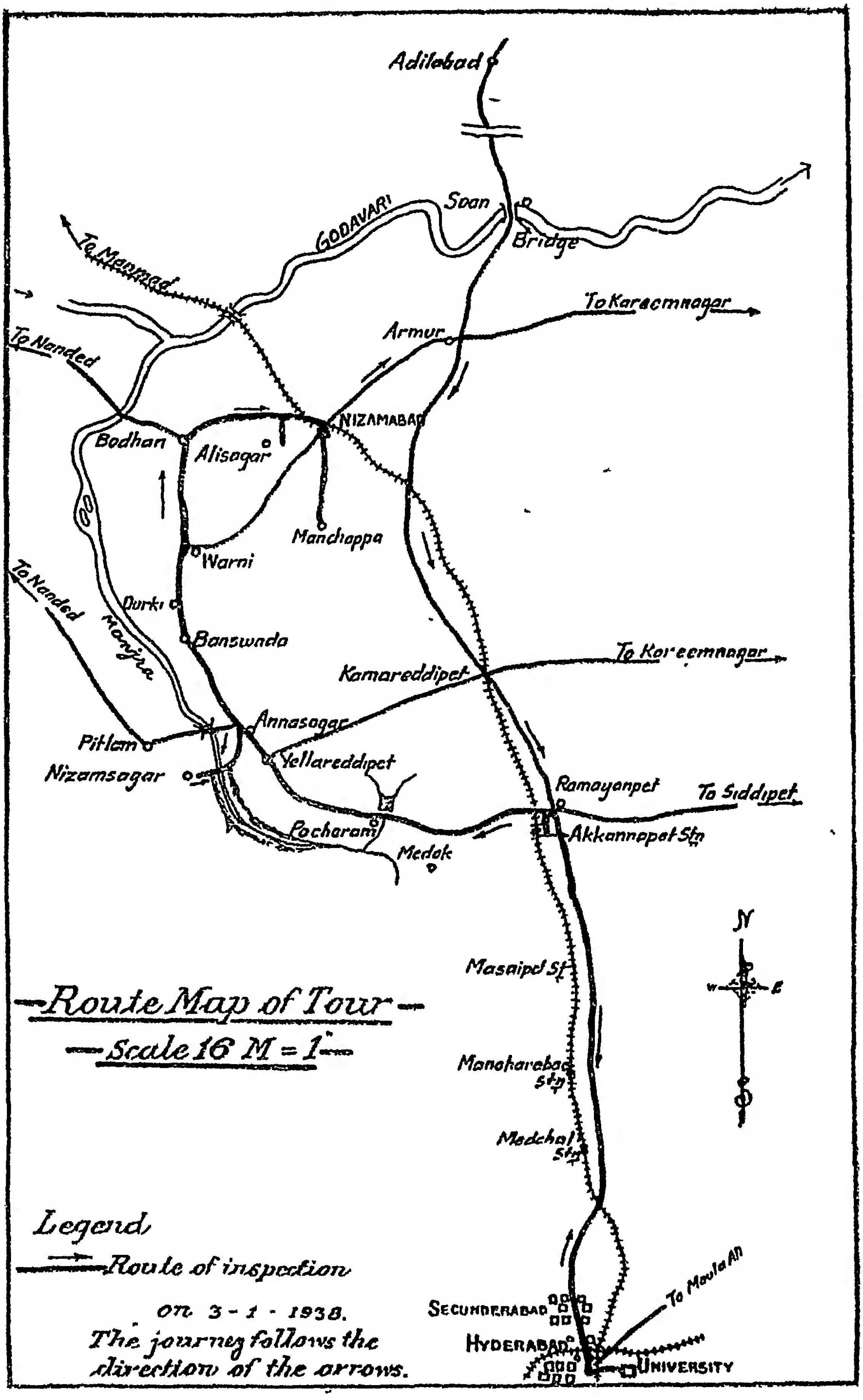
Class of road.	Metalled road.	Gravel road.
I	Rs. 670	Rs. 420
II	" 540	" 360
III	" 400	" 270

Out of the amount shown above two-thirds is utilised for renewal of surface and one-third for maintenance for metal roads. For gravel roads it is half and half.

DUST PROOFING THE ROADS.

Another advance which marks the road policy of the State is the system of dust proofing the roads in the district towns. The principle has been accepted that all district towns and commercial centres should have dust-proof roads within the inhabited area. The works are being taken up in the order of precedence. The dust proofiing is to consist of tar or asphalt painting or cement concrete slab, according to the intensity of the traffic.

Experiments are also being carried out with different kinds of dust proofing materials to evolve a cheap kind of dust proofing arrangement.



—Route Map of Tour—

—Scale 16 M = 1"—

Legend

Route of inspection on 3-1-1938.
The journey follows the direction of the arrows.

APPENDIX II.

BANQUET

at the

Town Hall, Public Gardens, Hyderabad (Deccan) at 8-15 p. m. on Saturday, January 1, 1938.

A joint Banquet of Members of the Indian Roads Congress and the Institution of Engineers (India) was held at the Town Hall, Public Gardens, Hyderabad (Deccan) at 8-15 p. m. on Saturday, the 1st January. 1938. Covers were laid for 354 members of both the Associations and distinguished guests, the principal of whom was the Right Honourable Nawab Sir Hyder Nawaz Jung Bahadur, P.C., Kt., B.A.. LL D.. D.C.L., President of H. E. H. the Nizam's Executive Council.

The Right Honourable Sir Nawab Hyder Nawaz Jung Bahadur proposed the toast of His Majesty the King Emperor.

(The toast was duly honoured.)

Maharaja Sir Kishen Pershad Bahadur, Yamin-us-Sultanat, proposed the toast of His Exalted Highness the Nizam of Hyderabad and Berar.

(The toast was duly honoured.)

Mr. Fakerji E. Bharucha, President of the Institution of Engineers (India), proposed the toast of the Right Honourable Nawab Hyder Nawaz Jung Bahadur.

(The toast was duly honoured.)

The Right Honourable Nawab Hyder Jung Bahadur in responding to the toast said: Mr. President, Ladies and Gentlemen, before I respond to your very kind toast, I should like to avail of the privilege of reading out the very gracious message sent by His Exalted Highness on this occasion. The Message reads:—

It has given me great pleasure to hear that in response to the invitation of the Engineers of my Government, you are holding the 18th Annual Session of the Institution of Engineers (India) and the Fourth Session of the Indian Roads Congress in the Capital City of my Dominions. I have little doubt that the deliberations of the two important Engineering Institutions, which you represent, will prove of considerable interest and value to the Engineering profession in India.

It is fully recognised that in promoting the moral and material welfare of India, it is the duty of us all to develop as rapidly as possible the great resources of the country. In securing this realisation the ability of its Engineers must play an important part.

I have great pleasure in sending you this Message to wish you godspeed in your work. I trust you will enjoy your visit to my Capital.

I am sure you will agree that this is a truly gracious message for which all of us assembled here are profoundly thankful.

I am greatly honoured, Mr. President, by having been given the privilege of being your guest at this Annual function of the Institution of

Engineers and of the Indian Roads Congress. I thank you, too, for the very kind references you have made in your speech to myself and to the part I have been privileged to take in the public life and the service of this State.

I had occasion recently, in opening the Indian Economic Conference, to lay stress on the value which we attach to assemblies and gatherings such as these which bring together men engaged in different parts of the country in a common pursuit and induce mutual conference and deliberation. Similarly, I welcome you to Hyderabad and am particularly happy to have had the pleasure of meeting you all who represent the Institution of Engineers and the Indian Roads Congress. Both these Institutions provide a common meeting ground for pooling experience and for exchange of ideas and while the services of the one, started seventeen years ago, have been recognized by the conferment of a Royal Charter, which, I am sure, the Institution of Enginneers regards as a high distinction, the Indian Roads Congress, started only recently, has in its own sphere assisted considerably in the growth and development of communications.

We attach the greatest value here to the Science of Engineering as, in the utilisation of the bounties of Nature, the opening up of undeveloped tracts, the cultivation of arid regions and the building of communications, engineering has conferred great blessings. We have, for that reason, a special College of Engineering attached to the Osmania University, while our Irrigation works, like the Nizamsagar, constructed entirely by Indian engineers under one who has earned for himself the reputation of being one of the most brilliant Irrigation Engineers in India, testify to the use we have made of the constructive side of your profession. We owe to your science, too, and to those who have mastered and applied it, the many bridges and the four thousand miles of roads which intersect these Dominions and make trade and traffic mobile. One thing that particularly strikes me in your works, whether they concern the construction of a dam or of a bridge or of a railway or of a road, is the corporate and collective endeavour which they generally represent, the union of intellectual effort, grappling with accurate and definite data and laws, with manual labour, skilled or unskilled. Such common effort for the comfort, the prosperity and the convenienc of man is a very noble passion, and, I am sure, it is the constant ideal of all members of the profession.

We have also, as you no doubt know, effected co-ordination between the means of communication in this State so far as transport is concerned. Road, rail and air traffic is being so regulated as to result in the one assisting the other in providing facilities to the passenger while a Vehicles Act has been brought into force as a result of which a fund has been ear-marked for the maintenance and construction of durable roads. Likewise railway construction requires planning if the needs of those areas are to be served which require being opened up for commercial, industrial or other economic purposes and I am glad to say that, on account of the co-operation in the State of the Revenue, the Railway and the Public Works Departments, such planning and co-ordination has been made successful. In addition, Hyderabad contributes to the Petrol Cess, the object of a portion of which is to develop the construction of good roads and create communication between different parts of India.

I hope you will enjoy your stay here and that you will take back with you good memories of the place and of its people. I hope, too, that

we shall be able to meet again and if you think of having this city again as your venue you may be certain that you will have a doubly warm welcome.

Mr. Mohammad Ahmed Mirza, Chief Engineer and Secretary to Government, Public Works Department, Hyderabad, in proposing the toast of the Indian Roads Congress spoke as follows :—

Sir Akbar Nawab Hyder Nawaz Jung Bahadur, Ladies and Gentlemen, I feel it a great honour to have been asked to propose the toast of the Indian Roads Congress. I take pleasure in taking advantage of this opportunity informally and before the session has actually begun to offer a very warm welcome to the distinguished delegates (and to Mr. Stubbs, the President-elect) who have assembled here tonight at this Banquet which, you will all agree with me, is a good beginning of the more serious affairs that are to engage our attention shortly. We are particularly pleased that this session at Hyderabad should synchronise with the Road Programme that the Government of His Exalted Highness the Nizam has initiated to regulate and expand its activities. In your itinerary in and beyond the City of Hyderabad, you will travel along roads which could safely be taken as specimens of the work that exists in these Dominions. You will also inspect the experimental lengths we have laid with a view to examining and observing these peculiarities and considering their suitability for adoption. While embarking upon this somewhat ambitious programme we have to be extremely cautious as we do not wish to emulate the unwarranted levity of the man in a famous story attributed to Mark Twain who was persuaded to put lightning conductor after lightning conductor at every possible point on his roof until the thunderstorm came and all the lightning in the heavens went for his house and wiped it out.

In a country like India, with our slender resources and a vast undeveloped field before us to cover, the money of the ryot has to be utilised to the fullest benefit. It is not mere wish or lofty enthusiasm that can achieve the desired results but the knowledge of the experts and skill of the highest order. Good and abiding results can be accomplished only by the co-ordination of work all over the country, joint deliberations and a concerted effort by all upon planned measures. The Indian Roads Congress alone can bring about and fulfil this function. Let us therefore pool at least our mental and physical, if not material, resources and evolve a plan through the agency of the Indian Roads Congress for the good of the country, as a whole, and the service of all its peoples.

Ladies and Gentlemen! I do not wish to detain you longer. I ask you to join with me in drinking to the well-being and continued activity of the Indian Roads Congress.

(The toast was duly honoured.)

Mr. S. G. Stubs, O.B.E., President of the Indian Roads Congress, in responding to the toast made a brief speech.

Nawab Ahsan Yar Jung Bahadur, Chief Engineer and Secretary to Government, Drainage and Irrigation Department, Hyderabad, proposed the toast of Our Guests.

(The toast was duly honoured).

The Honourable Nawab Mahdi Yar Jung Bahadur, M.A. (Oxon.), Political Member, H. E. H. The Nizam's Executive Council, replied to the toast.

APPENDIX III.

INDIAN ROADS CONGRESS.

List of Papers in Annual Proceedings.

Volume I—1934.

1. "Objects and Organisation of a Permanent Indian Roads Congress," by K. G. Mitchell, C.I.E., M.Inst.C.E.

1-(*a*) Recent Methods used for the Treatment of Roads with Bitumen and Tar in Delhi Province, by A. W. H. Dean, M.C., I.S.E.

2. The Trend of Development in the United Provinces in the matter of improving Road Surfaces with special reference to recent Experiments, by C. F. Hunter, M.Inst.C.E, A.M.I.E. (India).

3. Earth Road Construction and Maintenance by Machinery by G. W. D. Breadon.

4. Earth Road Development and Stabilisation with Gravel, by Lieutenant-Colonel A. V. T. Wakely, D.S.O., M.C., R.E.

5-(*a*) Progress made in the use of Tar and Bitumen in the Punjab since the last International Road Congress in Washington in October 1930, by S. G. Stubbs, O.B E., I.S.E.

5-(*b*) Notes on the Uses of Tar, Bitumens and Emulsions in the Punjab, by R. Trevor-Jones, M.C., A.M.Inst.C.E.

6. Asphalt Roads by G. G. C. Adami. B.A. (Cantab).

7. The Use of Cement Concrete for the Construction of Roads in the Bombay Presidency, by L. E. Greening.

8. Cement Concrete Roads, by W. J. Turnbull, B.Sc., M.Inst.C.E.

9. Concrete Roads in Hyderabad (Deccan), by M. A. Zeman.

10. Corrugation of Water-bound Macadam Road Surfaces in the Bombay Presidency, and a Cure, by Henry J. M. Cousens.

11. Notes on the Plant Used for Quarrying and Granulating and Operating Costs of the Gauhati-Shillong Road. Khasi and Jaintia Hills Division, Assam, by B. F. Taylor, R N.

12. Some Physical Aspects of Tyres and Roads, by G. L. W. Moss.

13. Test Tracks—A Suggestion, by C. D. N. Meares.

Volume II—1936.

14. Analysis of Delhi Road Traffic Census, by R. L. Sondhi, I.S.E.

15. A study of the Relationship between Vehicular Traffic and Road Surfaces as affecting the selection of an Economic Road Surface, by H. P. Sinha, I.S.E., and A. M. Abbasi.

16. Traffic Census and Road Diagrams, by Lt.-Colonel W. de H. Haig, D.S.O.

17. Economics of Road Maintenance, by S. Bashiram, I.S.E.

18. Necessity for Surface Treatment of Important Tourist lines and some Aspects of Economical Work in that direction, by V. S. Srinivasaragha Achariar Avl.

19. Treatment with Molasses of the Bangalore-Mysore Road, by Diwan Bahadur N. N. Ayyangar, B.A., L.C.E., M I.E.(Ind.), I.S.E.

20. The Road Problem in India with some Suggestions, by Colonel G. E. Sopwith.

21. General Review of the Results of Recent Road Experiments in India as revealed by Modern Practice, by K. G. Mitchell, C.I.E., I.S.E.

22. Road Research and Results, by C. D. N. Meares.

23-(*a*) Roads in Rural Areas (Village Roads), by Hony. Captain Rao Bahadur Choudhry Lal Chand, O.B.E., M.L.A.

23-(*b*) Gravel Roads, by Diwan Bahadur N. N. Ayyangar, B.A., L.C.E., M.I.E. (Ind.), I.S.E.

23-(*c*) Vitrified Bricks for Surfacing Roads in Deltaic Districts, by G. Gopala Acharya.

24. Oil as a Binder for Earth and Gravel Roads, by T. G. F. Hemsworth, B.A., B.A.I., I.S.E.

25. Cement-bound Roads, by W. J. Turnbull, B.Sc., M.Inst.C.E.

26. The Necessity for a Reasonably Uniform Standard Loading for Design of Concrete Bridges and a Suitable Loading for Such and Other Types of Bridges on Highways in India, by M G. Banerji, B A., B.E., A.M.Inst.M.&Cy.E., M.A E., F Sc.

27. Design of highway bridges. The necessity for an All-India Specification, by W A. Radice, B A., A.M.I.C E., G. Wilson, B.Sc. A M.I.C.E., and P. F. S. Warren, B.A., A.M.I.C.E.

28. Permissible Stresses in Concrete Bridge Design, by W. J. Turnbull, B.Sc., M.Inst.C.E.

29. Regulation and Control of Motor Transport in Mysore, by H. Rangachar, M.A.

30. The Construction of the Shillong-Jaintiapur Road in the Khasi Hills, Assam, by F. E. Cormack, I.S.E.

31. A Method of Rapid Road Reconnaissance, by Captain (now Major) W. G. Lang-Anderson, R.E.

Volume III—1937.

32. Some Notes on the lay-out of Rural and Suburban Roads in the Punjab, by R. Trevor-Jones, M.C., A.M.Inst.C.E.

33. Roads and Public Health in India with special reference to malaria, borrow pits, and road dust, by Raja Ram, B.Sc., A.M.Inst.C.E., F.R.San.I., M.I.E.(Ind.)

34. Further Notes on treatment of Roads with Bitumen and Tar in Delhi Province, by A. W. H. Dean, M.C., I.S.E.

35. Economy and Developments of Bonded Brick Concrete Roads, Plain and Reinforced, by A. K. Datta, B.E., M.I.E. (Ind.)., M.A.E.

36. Ways and Means of Improving the Bullock-Cart, by G. L. W. Moss.

37. Indian "Road-Aggregates," Their Uses and Testing, by R. L. Sondhi, I.S.E.

38. Submersible Bridge across Parbati River at Mile 231 Agra-Bombay Road, by Rai Bahadur S. N. Bhaduri.

39. Optimum Weight of Vehicles of extra Municipal Roads, by K. G. Mitchell, C.I.E., I.S.E.

Volume IV—1938.

A (*i*) A Method of Calculating the Stability of Braced Pile Piers, by Guthlac Wilson, B Sc., A.M.I.C.E., A.M.Am.Soc.C.E.

A (*ii*) The Dhakuria Lake Bridge, by Guthlac Wilson, B.Sc., A.M.I.C.E., A.M Am.Soc. C.E.

B. Franki Pile Foundations for Road Bridges, by W. A. Radice, B.A., A.M.I.C E., M.I.E. (India).

C. Reinforced Cement Concrete Bridges of 24 feet span constructed in Gwalior State, by Rai Bahadur S. N. Bhaduri, B.A., C.E., M I.E. (Ind.).

D. Reinforced Concrete Bridge Across the Godavari River at Shahgadh in Hyderabad State, by Dildar Hussain, B.E., M.I.E.(Ind.).

E. Safe Wheel Loads for Indian Roads, by K.G. Mitchell, C.I.E , I.S.E., and Jagdish Prasad, C.E.

F. Roads under Local Bodies and How to Maintain Them, by Rai Sahib Fateh Chand.

G. Corrugations on Road Surfaces, by G. B. E. Truscott.

H. An Aspect of Traffic Statistics by Ian. A. T. Shannon.

APPENDIX IV.

LIST OF MEMBERS OF THE INDIAN ROADS CONGRESS JULY 1938.

Abdul Hai, Mr.—Assistant Engineer, Asifabad, Hyderabad (Deccan).

Abid Reza Chaudhry, Mr.—Sub-Divisional Officer, Public Works Department, P. O. Goalpara.

Adalja, Mr. M. T.—Chief Engineer of Baroda State, Baroda.

Adke, Mr. A. S.—Engineer, District Local Board, Dharwar.

Adshetti, Mr. G. K.—6 Kotak House, Maharashtra Road, Karachi.

Ahsan Yar Jung Bahadur, Nawab—Chief Engineer and Secretary to Government Drainage and Irrigation Department, Hyderabad (Deccan).

Ali Ahmad, Mr.—Chief Engineer, Public Works Department, Shillong.

Anant Balwant Haval, Mr.—Ilakka Panchayat Engineer, Shukrawar Peth, Kolhapur.

Anwarullah, Mr.—Superintending Engineer, Osmania University Buildings Project, Hyderabad (Deccan).

Ariffuddin, Mr. Syed.—Superintending Engineer, Public Works Department, Aurangabad Circle, Hyderabad (Deccan).

Ayyangar, Diwan Bahadur N. N.—Chief Engineer of Mysore, Public Works Department, Bangalore.

Bagchi, Mr. C. C.—Sub-Divisional Officer, Lucknow University, Lucknow.

Bakshi, Mr. J.—Executive Engineer, Arrah.

Balakrishnan Ayyar, Rao Sahib N.—District Board Engineer, Tinnevelly.

Balwant Singh Budhiraja, Mr.—State Engineer, Nabha.

Balvant Vithal Vagh, Mr.—Road Engineer, Burmah-Shell Oil Distributing Company of India Ltd., Bombay.

Bamji, Mr. H. F.—Chief Electrical and Mechanical Engineer, Dawn Mills, Bombay 13.

Banerjee, Mr. M. G.—Controller of Stores, Calcutta Corporation, Calcutta.

Banerji, Mr. S. K.—Assistant Engineer. Rewa (Central India).

Barua, Mr. H. P.—Executive Engineer, Public Works Department, Gauhati.

Barua, Mr. K.—Assistant Engineer, Public Works Department, Barpeta, Assam.

Bashiram, Mr. S.—Superintending Engineer, I Circle, Rawalpindi.

Basu, Mr. H. L.—District Engineer, Balasore.

Bedekar, Mr. K. M.—Executive Engineer, Public Works Department, Karwar.

Bedekar, Mr. V. P.—State Engineer, Miraj Senior (Deccan States).

Bennett, Mr. C. M.—Executive Engineer, Public Works Department, Koraput (Orissa).

Beig, Mr. C. L.—Executive Engineer. Public Works Department, Chepauk, Madras.

Betterton, Mr. F. A.—Public Works Department, Ranchi.

Bhaduri, Rai Bahadur S. N.—Chief Engineer, Public Works Department, Gwalior.

Bhagat, Mr. D. G.—Assistant Engineer, c/o Special Road Engineer in Sind, Karachi.

Bhalla, Mr. Prem Nath.—District Engineer, Holkar State, Public Works Department, Garoth.

Bhandarkar. Mr. G. P.—Chief Engineer, Holkar State, Indore.

Bhargava, Mr. K. N.—Assistant Engineer, Roads, Alwar.

Bharucha, Mr. M. D.—C/o the All-India Construction Company, Phoenix Building, Bombay.

Bhatt, Mr. U. J.—State Engineer, Public Works Department, Bhavnagar.

Bhattacharya, Mr. H.—Assistant Engineer, Khulna.

Bhattacharya, Mr. N.—Executive Engineer, Buildings and Roads, Jaipur.

Bhave, Rao Saheb, V. G.—State Engineer, Sangli.

Bhuyan, Mr. M. N.—Assistant Secretary in the Public Works Department, Cuttack.

Bidhubusan Chaudhry, Mr.—Assistant Engineer, Public Works Department, Shillong.

Bishamber Dyal, Mr.—District Engineer, Rohtak.

Bisht, Mr. M. S.—Assistant Executive Engineer, Public Works Department, Naini Tal.

Blomfield, Mr. D. J.—Superintending Engineer, Public Works Department, Calcutta.

Bose, Mr. A. N.—Superintending Engineer, Central Circle, Calcutta.

Bose, Mr. B. N.—Assistant Engineer, Public Works Department, Calcutta.

Bose, Mr. K. M.—District Engineer, Sambalpur.

Bowers, Mr. P. L.—Chief Engineer, Jaipur State, Jaipur.

Breadon, Mr. G. W. D.—District Engineer, Gurdaspur.

Brebner, Sir Alexander.—Chief Engineer, Central Public Works Department.

Brij Mohan Lal. Mr.—Executive Engineer, Public Works Department, Lahore.

Brown, Mr. G. A. M.—Superintending Engineer, Public Works Department, Bannu.

Browne, Mr. C. A.—Executive Engineer, Motihari Division, Motihari, Bihar.

Bullen, Mr. E. G.—Officiating Executive Engineer, Southern Shan States. Soilem (Burma).

Burns Lawson. Mr. A.—The Hindustan Construction Company Limited, Bombay.

Burton, Mr. R. T.—C/o Standard Vacuum Oil Co., Karachi.

Chakravarti, Mr. S. N.—M.B.E., Municipal Engineer, Delhi.

Champalal, Mr.—Executive Engineer, Montgomery.

Chance, Mr. P. V.—Chief Engineer, Public Works Department, Central Provinces, Nagpur.

Chapman, Mr. H. V.—Executive Engineer, Burma Public Works Department, Bhamo.

Chatterjee, Mr. S. C.—Superintending Engineer, Central Circle, Calcutta.

Chatterton, Mr. K.—Manager, Structural and Bridge Building Department, Burn and Co , Ltd., Howrah.

Chenoy, Mr. Faridon. S.—Executive Engineer, His Exalted Highness the Nizam's Public Works Department, Shorat Munzil, Secunderabad.

Cherian, Mr. M. P.—Municipal Engineer, Tuticorin.

Chinchankar, Mr. K. B.—The New India Construction Company, Karad (Satara).

Chopra, Mr. A. N.—Executive Engineer, Public Works Department. Toungoo, Burma.

Chowdhry, Mr. S. P.—Assistant Engineer, Tezpur, Assam.

Chuttan Lal, Rai Bahadur.—Retired Chief Engineer, Dehra Dun.

Claringbould, Mr. E. J.—Engineer-in-Chief's Branch, Army Headquarters, Simla.

Clayton, Captain R.—Engineer-in-Chief's Branch, Army Headquarters, Simla.

Cocksedge, Mr. H. G.—Public Works Department, Dhubri, Assam.

Colabawala, Khan Bahadur J. R.—State Engineer, Khairpur Mirs, (Sind).

Cormack, Mr. F. E.—Executive Engineer, Public Works Department, Shillong.

Daftary, Mr. G. D.—Executive Engineer, Bombay Public Works Department, Poona.

Dalal, Mr. C. C.—C/o The Imperial Bank of India Limited, Hyderabad (Deccan).

Dam, Mr. S. C.—Executive Engineer, Jalpaiguri.

Dangoria, Mr. Chandulal C.—Hughes Town, Hyderabad (Deccan).

Das, Mr. B. C.—Sub-Engineer, Local Board, Tezpur, Assam.

Das Gupta, Mr. J. N.—Assistant Engineer, Delhi Municipal Committee, Delhi.

Das Gupta, Mr. N.—Asphalt Engineer, Standard Vacuum Oil Co., Calcutta.

Datta, Mr. A. K.—Consulting Engineer, Rohtas Industries Ltd., Dalmianagar, District Shahabad.

Datta, Mr. D. C.—Assistant Engineer, P. O. Mangaldai, Assam.

Datta, Mr. S. K.—Sub-Divisional Officer, South Shillong Sub-Division, Pynursla, Shillong.

Dave, Mr. D. P.—Sub-Divisional Officer, Akola.

De, Mr. B. C.—Sub-Engineer, Public Works Department, Silchar, Assam.

Dean, Mr. A. W. H.—Superintending Engineer, New Delhi.

Desai, Mr. D. S.—C/o Messrs. Braithwaite & Co. (India), Ltd., Calcutta.

Devasthala, Mr. K. B.—District Engineer, District Council, Yeotmal, C. P.

Devi Doyal, Mr.—Executive Engineer, Public Works Department, Dibrugarh (Assam).

Dighe, Mr. V. A.—Chief Engineer, Janjira State, Janjira Murud.

Dilbagh Singh Deshi, Mr.—State Engineer, Sangrur (Jind State).

Dildar Hussain, Mr.—Assistant Chief Engineer, His Exalted Highness Public Works Department, Hyderabad (Deccan).

Dogra, Mr. R. N.—Apprentice Engineer, 1st Lahore Provincial Division, Lahore.

Doshi, Mr. A. G.—State Engineer, Radhanpur.

Doshi, Mr. M. M.—C/o The Indian Hume Pipe, Lucknow.

Dunbar, Mr. H. M.—C/o The Concrete Association of India, Bombay.

Duraiswami Ayyangar, Mr. M. S.—Executive Engineer, Kottayam, Travancore.

Duraiswami, Mr. M. R.—Municipal Engineer, Kumbakonam.

Durrani, Mr. N.—District Board Engineer, Bobbili, Vizigapatam District

Dutt, Mr. G. N.—Sub-Divisional Officer, Public Works Department, Kohima (Naga Hills, Assam).

Eapen, Mr. M.—Municipal Engineer, Bezwada.

Eastmond, Mr. A. — M.C., Executive Engineer, Kumaun Division Naini Tal.

Eccleston, Mr. W. T.—Executive Engineer. Multan Provincial Division, Multan.

Edibam, Mr. N. R.—D57/35, Aurangabad Road, Benares.

Edwin, Mr. J. W.—Assistant Engineer, C. & M. Station Municipality Bangalore.

Endlaw, Mr. D. N. Civil Aviation Division, Bombay.

Fairs, Mr. G.—Sub-Divisional Officer, Bannu Civil Works Sub-division, Bannu.

Faqir Mohd. Khan, Mr.—Executive Engineer, Public Works Department Dehra Ismail Khan.

Farqui, Khan Bahadur M. Z. A.—Executive Engineer, Central Public Works Department.

Fateh Chand, Rai Sahib Lala.—Secretary-Engineer, District Board, Bijnor.

Fetters, Mr. J. M.—District Representative of Caterpillar Tractor Co., C/o American Consul, Calcutta.

Fielder, Mr. J. C.—C/o Messrs. Turner Morrison and Co. Ltd., Calcutta.

Fitzherbert, Mr. R. A.—Superintending Engineer, Public Works Department, Bombay.

Gandhi, Rao Bahadur K. J.—State Engineer, Junagarh, (Kathiawar),

Gangadhara, Mr. K. S.—Assistant Engineer, No. 2 Sub-division, Challakere

Garga, Mr. M. L.—Municipal Engineer, Agra.

Ghanekar, Mr. Y. K.—Assistant Engineer, Nagpur Improvement Trust, Nagpur.

Gharpure, Mr. A. V.—C/o The Indian Hume Pipe Co. Ltd., Delhi.

Ghose, Mr. S. K.—Assistant Engineer, Public Works Department, Muzaffarpur.

Gilbert, Mr. L. B.—Officiating Consulting Engineer to the Government of India (Roads).

Gilmore, Mr. E. F. G.—Director, Industrial Research Bureau, Indian Stores Department, New Delhi.

Gnanaprakasam, Mr. N. T.—L.F. Assistant Engineer, Bezwada.

Gobindaswamy Naidu, Mr. R. B.—Assistant Engineer, Pithapuram.

Goghari, Mr. D. W.—Retired State Engineer, Bhavnagar.

Golwala, Mr. P. E.—Civil Engineer, C/o Chief Engineer, Bombay Port Trust, Ballard Estate, Bombay.

Gopala Acharya, Mr. G.—Assistant Engineer, Public Works Department, Gudivada Kistna District.

Gopalan, Mr. M.—Special Superintending Engineer, Capital Works Circle, Kachiguda, Hyderabad (Deccan).

Gopal Das, Mr.—Sub-Divisional Officer, Public Works Department, Hissar.

Gopal Singh Nat, Mr.—C/o Garrison Engineer, New Construction, Wana.

Goswami, Mr. S. M.—Assistant Inspector of Local Works, P.O. Motihari, Champaran.

Gough, Mr. D.—Representative of the Society of Motor Manufacturers and Traders Ltd., Bombay.

Graham, Captain R. C.—Executive Engineer, Public Works Department, Peshawar.

Gray, Mr. T. Campbell.—Shalimar Tar Products Ltd., Madras.

Griffiths, Mr. W. A.—Burmah-Shell Oil Co., Ltd., Calcutta.

Gue, Rai Sahib, K. C.—District Engineer, Jalpaiguri, Bengal.

Gue, Mr. T. C.—Chief Engineer, Rewa State.

Guha, Mr. J. C.—Executive Engineer, P. W. D., Deccan Division, P.O. Ramna, Bengal.

Gunnell, Captain W. B.—C/o Messrs. Ford & Macdonald Ltd., New Delhi.

Gupta, Rai Sahib J. N.—Sub-Divisional Officer, Special Works Sub-Division, Shillong.

Gupta, Mr. M. C.—Municipal Engineer, Allahabad.

Gupta, Mr. S. M.—Assistant Engineer, Public Works Department, Pegu, Burma.

Guruswami, Mr. S.—Assistant Inspector of Local Works, Muzaffarpur.

Haig, Lt.-Col. W. deH.—D S.O., Chief Engineer, Public Works Department, B. & R. Branch, United Provinces, Lucknow.

Hain, Mr. H. W. T.—Managing Director, Braithwaite & Co. (India) Ltd., Calcutta.

Hainsworth, Captain J. R.—Executive Engineer, Peshawar.

Hall, Captain G. F.—C.I.E., M.C., Chief Engineer, Public Works Department, Ranchi.

Hanmanth Rao, Mr. C.—Divisional Engineer, Parbhani.

Hardit Singh, Mr.—Sub-Divisional Officer, Charsadda.

Hardlikar, Mr. J. C.—Executive Engineer, Public Works Department, Parbhani (Nizam's Dominions).

Hari Chand, Rai Sahib—Concrete Association of India, New Delhi.

Hari Shankar Sharma, Mr.—District Board Engineer, Meerut.

Harris, Mr. H. A.—Executive Engineer, Lyallpur Provincial Division, Lyallpur.

Harris, Mr. J.—District Board Engineer, Saharanpur.

Harrison, Mr. C. P. M.—Chief Engineer, Department of Communications and Works, Calcutta.

Hewitt, Mr. R. C. L.—Superintending Engineer, Orissa Circle, Cuttack.

Hodgson, Mr. E. S.—Broadway Buildings, Westminster, London.

Hogshaw, Mr. F. H.—Superintending Engineer, Calcutta.

Hughes, Mr. H.—Chief Engineer, Burma Public Works Department, Rangoon.

Hunter, Mr. C. F.—Dy. Chief Engineer. Public Works Department, B. & R. Branch, Lucknow.

Iqbal Narain Mehta, Mr.—Municipal Engineer, Multan.

Ishtiaq Ali, Mr.—Assistant Municipal Engineer, Delhi.

Jagdish Prasad, Mr.—Assistant to the Consulting Engineer to the Government of India (Roads), Simla.

Jagmohanlal Bhatnagar, Mr.—State Engineer, Jhalawar State, Brijnagar, (Rajputana).

Jardine, Mr. A.—Director, Jessop & Co. Ltd., Calcutta.

Jayswal, Rai Bahadur U. S.—District Engineer, Muzaffarpur.

Jivarajani, Mr. M. R.—State Engineer, Porbander.

Jivarajni, Mr. P. R.—Assistant Engineer, Jacobabad.

Joglekar, Mr. G. D.—Supervisor, District Local Board, Thana.

Jones, Mr. F. T.—C.I.E., M.V.O., Chief Engineer, Central Public Works Department, Simla/New Delhi.

Joshi, Mr. N. S.—Assistant Engineer, 877 Sadashiv Peth, Poona.

Joti Prasad, Mr.—District Engineer, Narsinghpur, (C. P.).

Jussawala, Mr. J. R.—State Engineer, Cambay.

Kamesam, Mr. S.—Forest Research Institute, Dehra Dun.

Kanhere, Mr. V. P.—State Engineer, Bhor State.

Karve, Mr. K. V.—Assistant Engineer, Public Works Department, Shankarapuram, Bangalore City.

Katkoria, Mr. C. R.—State Engineer, Cutch State, Bhuj.

Katrak, Mr. M. M.—153-C, Sappers Line, Secunderabad.

Keatinge, Mr. H. A.—Executive Engineer, Public Works Department, Rajshahi, Bengal.

Kelly, Mr. R. J.—Assistant Executive Engineer, Services Division, Central Public Works Department, New Delhi.

Kerr, Mr. J. Oldfield.—C/o Burmah-Shell, Karachi.

Kerr, Mr. R. A.—C/o The Burmah Oil Company, Ltd., Rangoon.

Khairuddin Ahmed, Mr.—Executive Engineer, Public Works Department, Hyderabad (Deccan).

Khan, Mr. N. M.- Assistant Engineer, Special Division, Khiratabad, Hyderabad (Deccan).

Khanna, Mr. I. N.—Asphalt Road Engineer, Standard Vacuum Oil Co., Engineers' House, Chhipiwara, Delhi.

Khanna, Mr. Prem Nath—District Board Engineer, Muttra.

Khatri, Mr. K. C.—Sub-Divisional Officer, Public Works Department, Shahbazgarhi, Tehsil Mardan.

Kidar Nath, Rai Sahib.—Executive Engineer, Public Works Department, B. & R. Branch, Jullundur Cantt.

Kikkeri, Mr. S. A.—4 Club House Road, Madras.

Kirk, Mr. E. S.—C/o Braithwaite Burn & Jessop Construction Company, Calcutta.

Korni, Dr. M. A.—Chief Engineer, Reinforced Concrete Department, Bird and Co. Ltd., Calcutta.

Kunte, Mr. Vaman J.—State Engineer, Jamkhandi.

Kurian, Mr. J.—Engineer to the Corporation of Madras, Madras.

Kutty Krishnan, Mr. O. C.—Roads Engineer, The Standard Vacuum Oil Co. Madras.

Kynnersley, Mr. T. R. S.—The Associated Cement Companies Ltd., Bombay.

Lakshminarasimhaiya, Mr. N.—Executive Engineer, Bangalore.

Lakshminarayana Aiyar Venkatakrishnan, Rao Bahadur.—Superintending Engineer, Tanjore Circle, Tanjore.

Lakshminarayana Rao, Mr. A.—District Board Engineer, Masulipatam, Kistna District.

Lang-Anderson, Major W. G.—Superintending Engineer, Public Works Department, Peshawar.

Lawley, Mr. W.—Executive Engineer, Public Works Department, Mardan.

Lekh Raj, Mr.—Civil Engineer, Kapurthala State, Kapurthala.

Lloyd, Mr. M. E.—Asphalt Engineer, Standard Vacuum Oil Co., Calcutta.

Lokanatha Mudaliar, Mr. T.—District Board Engineer, Coimbatore.

Lokendra Bahadur, Mr.—Executive Engineer, His Exalted Highness the Nizam's Public Works Department, Bidar.

Mackenzie, Mr. R. H. T.—Chief Engineer, Bikanir State, Bikanir.

Madhav, Mr. S. K.—Assistant Engineer, City Municipality, Indore.

Madhava Rao, Ch.—L. F. Assistant Engineer, Ongole District Board, Bapatla, Guntur District.

Madho Prasad Srivastava, Mr.—District Board Engineer, Lucknow.

Mahabir Prasad. Mr.—Deputy Chief Engineer, Public Works Department, Lucknow.

Malhotra, Mr. B. R.—Assistant Engineer, Public Works Department, Peshawar.

Malik, Sardar Bahadur, T. S.—C.I.E., Superintending Engineer, Central Public Works Department, New Delhi.

Manohar Nath, Mr.—Executive Officer, Municipal Board, Meerut.

Marker, Mr. H. F.—Superintending Engineer, Mysore Public Works Department, Bangalore.

Mathew, Mr. P. G.—District Board Engineer, Nellore South, Nellore.

McIntosh, Mr. R.—Executive Engineer's Bungalow, Waltair, Vizagapatam District.

Mckelvie, Mr. G. M.—Executive Engineer, Central Public Works Department, Dehra Dun.

Meares, Mr. C. D. N.—C/o Standard Vacuum Oil Co., Calcutta.

Mehdi Ali, Mr. Mirza—District Water Works Hanamkunda (Nizam's Dominions)

Mehra, Mr. S. R.—Sub-Divisional Officer, Multan.

Mehta, Mr. Jagmohandas T.—Town Roads Supervisor, Vadva, (Bhavnagar State)

Mehta, Mr. N. N.—Kennedy Cottage, Central Division, Simla.

Meswani, Mr. V. M.—Indian Hume Pipe Company, Lucknow.

Mitchell, Mr. K. G.—C.I.E., Consulting Engineer to the Government of India (Roads), Simla.

Modak, Mr. N. V.—City Engineer, Bombay Municipality, Fort, Bombay.

Modi, Mr. A.K.—The Navsari Electric Supply Company, Ltd., Navsari.

Mohammad Abdul Kayyar Khan, Mr.—Divisional Engineer, His Exalted Highness the Nizam's Dominions, Kharimnagar.

Mohammad Abu Turab, Mr.—Superintending Engineer, Public Works Department, Medak, (Nizam's Dominions).

Mohammad Assadullah, Mr.—Divisional Engineer, His Exalted Highness the Nizam's Dominions, Bhir.

Mohammad Ibrahim, Mr.—Executive Engineer, Public Works Department, Asifabad, Hyderabad (Deccan).

Mookerjee, Mr. B. N.—C/o Martin & Company, Calcutta.

Mookerjee, Mr. R. N.—8/3 Loudon Street, Calcutta.

Morgan, Mr. I.—103 Clive Street, Calcutta.

Morris, Mr. A. E. C.—Branch Manager, McKenzies Limited, Esplanade, Madras.

Morris, Mr. W. H.—C/o The Wardle Engineering Company, Secunderabad.

Mufti, Mr. M. I. D.—Garrison Engineer's Office, Fort William, Calcutta.

Mukerjee, Mr. A. C.—Executive Engineer, Provincial Division, Lucknow.

Mukerji, Mr. U. N.—Executive Engineer, 76 Parashor Road, P.O. Kalighat, Calcutta.

Mukherji, Mr. P. K.—District Board Engineer, Cocanada, (East Godavari).

Murari Lal, Mr.—Assistant Engineer, Public Works Department, Rohtak.

Murphy, Mr. W. H.—M.B.E., Municipal Executive Engineer, Bangalore.

Murrell, W. L.—Superintending Engineer, Chhota Nagpur Circle, Ranchi.

Nadirshah, Mr. E. A.—Hydraulic Engineers Department, Improvement Trust Building, Bombay.

Nagarsheth, Mr. M. P.—Nagarsheth's Street, Broach, Bombay Presidency.

Nageswara Ayyar, Mr. A.—Special Engineer for Road Development, Madras.

Nambiar, Mr. K. K.—District Board Engineer, South Kanara, Mangalore.

Nanda, Mr. B. D —Divisional Engineer, Banihal Road Division, Udhampur.

Naqvi, Mr. M. H.—Executive Engineer, Public Works Department, Bhir, Hyderabad (Deccan).

Narasimha Iyengar, Mr. N.—Assistant Engineer, No 2 Sub-Division, Mysore Public Works Department, Dodballapur.

Narasimha Iyer, Mr. M. K.—Executive Engineer, Malleswaram, Bangalore.

Narasimham, Mr. J. S.—31 Malak Pet, Hyderabad (Deccan).

Narasimha Shenoy, Mr. B.—District Board Engineer, Calicut, Malabar.

Narayanamurty, Mr. B.—L. F. Assistant Engineer, Vizianagram.

Narayana Nayar, Mr. P. T.—Special District Board Engineer, Calicut, Malabar.

Narayanaswami, Mr. S.—District Board Engineer, North Ramnad, Tirupathur.

Nayar, Mr. D. P.—Sub-Divisional Officer, Public Works Department, B. & R. Branch, Lahore.

Naziruddin, Mr. K.—Executive Engineer, Berhampore (Ganjam).

Newton. Mr. B. St. J.—Officiating Superintending Engineer, Raipur, C. P.

Nicolson, Mr, J. F. H.—Chief Public Works Officer, Federated Shah States, Taunggyi Burma.

Nightingale, Mr. A. W.—Superintending Engineer, Bellary (Madras Presidency).

Nilsson, Mr. D.—Chief Engineer, and Director, J. C. Gammon & Co. Bombay.

Northey, Lt. Col. H. S.—Superintending Engineer. Public Works Department, P. O. Modigere, Kadur District.

Nougerede, Mr. C. E. De la.—Assistant Garrison Engineer, Shillong.

Oram, Mr. A.—Chief Engineer, Public Works Department, Peshawar.

Pancholi, Mr. D. B.—State Engineer, Dhrangadhra State, Dhrangadhra.

Parikh, Mr. H. B.—Special Road Engineer in Sind, Public Works Department, Karachi.

Parmara, Mr. S.—A. P. Sen Road, Lucknow.

Patel, Mr. B. D.—Executive Engineer, Special Roads Division, Hyderabad (Sind).

Patel, Mr. M. R.—Executive Engineer, Navsari (Baroda State)

Pearce, Mr. E. O.—Departmental Manager, Engineering, Bird & Co., Calcutta.

Pennel, Mr. K. E. L.—M.C., Chief Engineer and Secretary, to the Government of Assam. Public Works Department, Shillong.

Pereira, Mr. R. A.—District Board Engineer, Erode, South India.

Plumley, Mr. D. J. — State Engineer, Jagdalpur.

Powell, Mr. J. G.—Chief Engineer and Secretary to the Government of Bihar, Public Works Department, Patna.

Radice, Mr. W. A.—Braithwaite Burn and Jessop Construction Company, Calcutta.

Raghavachary, Mr. K. S.—Assistant to the Special Engineer, Road Development, Madras.

Rajam, Mr. M. K.--Assistant Engineer, Public Works Department, Arjanapur (Mysore)

Raj Mohan Nath, Mr.—Assistant Engineer, Public Works Department, Nowgong, Assam.

Raju, Mr. P. Venkataramana—Executive Engineer, Public Works Depart ment, Bezwada.

Ramamurti, Mr. K. S.—District Board Engineer, Guntur District, Ongole.

Ramamurty Pantulu Guru, Mr. K.—Public Works Supervisor, Vizagapatam Municipality, Vizagapatam.

Ramanujacharya, Mr. S.—Assistant Engineer, Public Works Department, Anantapur, Madras Presidency.

Ramanujam, Mr. M.A.—Assistant Engineer, Head Quarter Range, Mysore.

Ramaswami Iyer, Mr. T. R.—Ramnad District Board Engineer, Tiruvanamalai.

Ramaswamy, Mr. H.—District Board Engineer, Dharwar, Bombay Presidency.

Ramchandra Subrahmanyam, Mr.—Executive Engineer. Madura Municipality, Madura.

Ramesh Chandra, Mr.—Thomason College, Roorkee.

Ranade, Mr. D. H.—B E. c/o Messrs. Ranade Brothers, Engineers and Contractors. Poona 2.

Rangaswami, Mr. K.—State Engineer, Pudukkottai State, Pudukkottai.

Rangaswami, Mr. V. N.—Road Engineer, Burma-Shell Co., Madras.

Rangaswami, Mr. V. S.—Assistant Engineer, District Board, West Tanjore.

Rangaswamy, Rao Sahib M. A.—District Engineer, Darbhanga.

Rao, Mr. D. V.—Executive Engineer, Well Sinking Department, Shorapur, District Gulbarga.

Ratnagar. Mr. R. D.—Executive Engineer, Public Works Department, Jubbulpore.

Ray, Mr. G. P.—District Engineer, Puri.

Rege, Mr. D. Y.—C/o Standard Vacuum Oil Company, Bombay.

Rege, Mr. S. B.—Executive Engineer, Ratnagiri Division, Ratnagiri.

Roberts, Mr. S. A.—Partner, Bird & Co, Calcutta.

Ross, Mr. G. M.—Chief Engineer and Secretary to the Goverment of North West Frontier Province, Public Works Department, Peshawar.

Rowlands, Mr. W. H.—Technical Assistant, Burmah-Shell Oil Co., Ltd., New Delhi.

Roy, Mr. C. B.—Executive Engineer, Chhindwara.

Sadarangani, Mr. V. H.—Professor of Civil Engineering. College of Engineering, Madras, Saidapet.

Safdar Ali Shareef. Mr.—Assistant Engineer, Public Works Department, Hyderabad (Deccan).

Sahney, Mr. J. C.—Assistant Engineer, Public Works Department, Gonda.

Saksena, Mr. C. P.—Assistant Engineer, Rewa State, Annuppur.

Sanjana, Mr. N. P.—Engineering Assistant, Chief Engineer's Office. Bombay Port Trust, Fort, Bombay.

Sankaram, Mr. G. B.—L. F. Assistant Engineer, Gudivada.

Sant Ram Shagal, Rai Sahib.—State Engineer, Mewar State, Udaipur.

Sarabhoja, Mr. N.—Superintending Engineer, Irrigation Circle (K. E. S. Works) Bangalore.

Sarkar, Mr. R. K.—Municipal Engineer, Lucknow.

Sastri, Mr. N. A.—1308 Kutbiguda Road, Sultan Bazars, Hyderabad (Deccan).

Satyanarayana, Mr. B.—District Board Engineer, Rajahmundry. East Godavary.

Sayoji Rao, Mr. H. R.—Assistant Engineer, District Board, Kistna, Masulipatam

Scaldwell, Mr. R. W.—Superintending Engineer, Mysore Circle. Mysore.

Scott, Mr. G. E.—Superintending Engineer, Rangoon.

Seshagiri Rao, Mr. G.—Executive Engineer, Krishnaraja Sagara, Mysore State.

Shah, Mr. M. J.—Road Engineer, Rajkot State, Rajkot.

Shah, Mr. V. J.—Engineer to Khan Bahadur M. A. K. Mackawee, O B.E, Govt. Contractor, Maidan Road, Camp Aden, Arabia.

Shahani, Mr. C. M.—C/o Braithwaite & Co. (India) Ltd., Calcutta

Shahani, Mr. H. M.—Supervisor of Works, Hyderabad Municipality, Hyderabad (Sind).

Shanker Rao Panje, Mr.—District Board Engineer, Anantapur.

Shannon. Mr. Ian. A. T.—Technical Expert, Burma-Shell Co., Madras.

Sharma, Mr. S. S.—Assistant Engineer. Benares Provincial Division, Benares.

Shivdasani, Mr. K. J.—Chief Officer and Engineer, District Local Board Larkana (Sind).

Sinha, Mr. H. P.—Executive Engineer, Central Public Works Department, New Delhi.

Sirajuddin. Mr. P.—District Board Engineer, Vellore.

Smith, Lt.-Col. H. C.—M.C., O.B E., General Secretary, Indian Roads and Transport Development Association, Bombay.

Sondhi, Mr. R. L.—Executive Engineer, Lahore.

Sopwith, Colonel G. E.—General Manager, Shalimar Tar Products Ltd., Calcutta.

Sowani, Mr. D. G.—Executive Engineer, Kolhapur State, Kolhapur.

Sri Narain, Rai Bahadur—Chief Engineer, Cawnpore Improvement Trust, Cawnpore.

Sridhar Rao, Mr.—District Board Assistant Engineer, Tellichary, Malabar.

Srinivasachari, Mr. M. A.—Retired Superintending Engineer, Basavangudi, Bangalore City.

Srinivasamurti, Mr. K. V.—Assistant Engineer, No. 1 Sub-division, Public Works Department, Mysore.

Srinivasan, Mr. K.—L. F. Special Assistant Engineer, Vizianagram.

Srinivasa Raghava Acharyar, Mr. V. S.—District Board Engineer, Trichnopoly.

Stanier, Mr. T. W.—C/o Aveling-Barford. Ltd., Grantham, England.

Stevens, Major A. E.—Officiating Commanding Royal Engineer, Western Command, Karachi.

Stuart, Captain James—Executive Engineer, Public Works Department, Bannu.

Stuart Lewis, Mr. A.—The Concrete Association of India, Calcutta.

Stubbs, Mr. S. G.—O.B.E., Chief Engineer, and Secretary to the Government of Punjab, Public Works Department, Lahore/Simla E.

Subba Rao, Mr. K.—Municipal Engineer, Guntur.

Subba Rao, Mr. N.—Superintending Engineer. Mysore Circle, Mysore.

Sujan, Mr. S. B.—District Engineer, Concrete Association of India, Karachi.

Sukhatankar, Mr. V. M.—District Engineer, District Local Board, Belgaum.

Sundaram Pillai, Mr. N. P.—District Board Engineer, Negapatam

Sundaresan, Mr. T. V.—Assistant Garrison Engineer Colaba, Bombay 5.

Sunderlal, Rai Bahadur—Superintending Engineer, Public Works Department, Nagpur.

Surati, Mr. H. M.—Divisional Engineer, Roads, Hyderabad (Deccan).

Thorpe, Mr. A. N.—Consulting Engineer, Dholpur State, Dholpur.

Tirumalaiswami Ayyar, Mr. K.—District Board Engineer. Saidapet.

Todd, Mr. J. M.—Executive Engineer, Moulmein Division, Public Works Department, Moulmein, Burma.

Tonks, Mr. H. J.—Officiating Chief Engineer, Rangoon Corporation, Rangoon.

Trevor-Jones, Mr. R.—M.C., Superintending Engineer, Third Circle, Lahore.

Tripathi, Mr. S. N.—Assistant Engineer, Public Works Department, Chhindwara.

Trollip, Mr. A. S.—General Manager, The Bombay Electric Supply and Tramway Co, Ltd., Bombay.

Truscott, Mr. G. B. E.—Chief Engineer, Public Works Department, Travancore.

Tulsidas Banerji, Rai Sahib—Assistant Garrison Engineer, Jubbulpore.

Turnbull, Mr. W. J.—C/o Shalimar Tar Products (1935) Ltd., Bombay.

Tweed, Mr. Rathlin, J. C.—Works Manager, Braithwaite & Co. (India) Ltd., Calcutta.

Ulfat Rai Chaddha, Mr.—Military Engineering Service, Nowshera Cantt.

Uttam Chand Gaur, Mr.—Officiating Garrison Engineer, Military Engineering Services, Quetta.

Vaishnav, Mr. S. G.—Personal Assistant to the Chief Engineer, Baroda.

Vakil. Rai Sahib N. H.—District Engineer, P. O. Motihari, Champaran.

Varma, Rai Bahadur A. P.—Chief Engineer, Patiala State, Patiala.

Varma, Mr. R. L.—Executive Engineer, Public Works Department, Tezpur.

Vasvani, Mr. G. B.—Assistant Engineer, Roads, Karachi Municipality.

Venkatasubrahmanya Iyer, Mr. C. S.—District Board Engineer, Kurnool.

Vesugar, Mr. J.—Under Secretary to the Government of Punjab, Public Works Department, Buildings and Roads Branch, Lahore.

Vipan, Mr. A.—C.I.E., Chief Engineer, Government of Orissa, Public Works Department, Cuttack.

Wadley, Mr. K. L. H.—Executive Engineer, Simla Central Division, Simla.

Wale, Mr. N. D.—Engineer, Municipal Borough, Hubli, District Dharwar.

Walker, Brigadier E. C.—Chief Engineer, Southern Command, Poona.

Walker, Mr. W. F.—Executive Engineer, Public Works Department, Meerut.

Warren, Mr. P. F. S.—Director, Jessop and Co. Ltd., Calcutta.

Wellwood, Mr. F. D.—Chief Engineer, Mayurbhanj State, Baripade.

Whishaw, Major W. B.—O.B.E., M.C., R.E., Engineer-in-Chief's Branch, Army Headquarters, Simla.

Whitby, Mr. A. B.—Executive Engineer, Public Works Department, Hoilem Burma.

Willcocks, Mr. H.—Superintending Engineer, Central Public Works Department, New Delhi.

Wilson, Mr. G.—Engineer, Braithwaite Burn and Jessop Construction Co., Calcutta.

Winckler. Mr. L. A. H.—Executive Engineer, Mysore Public Works Department. Kadur.

Wooltorton, Mr. F. L. D.—Executive Engineer, Shwebo Division, Shwebo, Burma.

Zutshi, Mr. M. N.—Engineer, District Board, Gorakhpur.

LIST OF ASSOCIATE MEMBERS OF THE INDIAN ROADS CONGRESS, JULY 1938

Anderson, Mr. J. P.—Dunlop House, Calcutta.

Armitage, Mr. Edgar.—C/o Messrs. Grindlay and Company. Bombay.

Barnhart, Mr. E. W.—District Representative of Caterpillar Tractor Co., C/o The American Consulate, Calcutta.

Chinoy, Mr. Nurmohamed M.—C/o The Bombay Garage, Chowpatty, Bombay.

Davidson, Mr. J. C. F.—C/o Messrs. Bird & Co., Oriental Buildings. Lahore.

Ford. Mr. T. S.—C/o The General Motors (India) Ltd., Bombay.

Gupta, Mr. T. N.—96 Civil Lines, Jhansi.

James, Mr. Hugh—Burma Shell House, Ballard Estate, Bombay.

Kataimal, Mr. C. L.—State Engineer, Orcha State, Tikkamgarh.

Kerr, Mr. W. H.—District Sales Manager for Northern India of Bitumen Emulsions (India) Ltd., C/o The Rawalpindi Club, Rawalpindi.

Marschalko, Mr. Th. C.—Chief Engineer, Texas Company (India) Ltd., Bombay.

Mohd. Khan, Mr.—Government Contractor, New Gate, Rampura, Peshawar.

Moss, Mr. G. L W.—Technical Service Manager, Dunlop (India) Ltd., Calcutta.

Ormerod, Mr. H. E.—Forbes Building, Home Street, Bombay.

Pennycuick, Mr. J. R.—C/o Messrs. Jackson Company, Hamilton House, Grahm Road, Ballard Estate, Bombay.

Senapathy, Mr. A. G.—Engineering Contractor. 2 Bridge Road, Bangalore.

Smith, Mr. J. W.—C/o Standard Vacuum Oil Company, Calcutta